BuMines OFR 79-86

PB86-246568

A minerals data analysis report
MAY 1985

CAPITAL AND OPERATING COST ESTIMATING SYSTEM HANDBOOK FOR ALUMINA REFINERY FACILITIES

BuMines Open File Report 79-86

Contract J0245003
Raymond Kaiser Engineers Inc.

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA. 22161

DISCLAIMER NOTICE

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U.S. Government.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. BuMines OFR 79-86	2.	3. Recipient's Accession No. PB86-246568/AS

4. Title and Subtitle

Capital and Operating Cost Estimating System Handbook for Alumina Refinery Facilities

5. Report Date

May 1985

6.

7. Author(s)

R. F. Neider

8. Performing Organization Rept. No.

84125-300

9. Performing Organization Name and Address

Raymond Kaiser Engineers, Inc.
P.O. Box 23210
Oakland, CA 94623-2321

10. Project/Task/Work Unit No.

84125-300

11. Contract(C) or Grant(G) No.

(C) J0245003

(G)

12. Sponsoring Organization Name and Address

Office of Assistant Director--Mineral Data Analysis
Bureau of Mines
U.S. Department of the Interior
Washington, DC 20241

13. Type of Report & Period Covered

Contract research, July 17, 1984--Feb. 1986

14.

15. Supplementary Notes

Approved for release August 6, 1986.

16. Abstract (Limit: 200 words)

This report provides the methodology for developing capital and operating costs related to an alumina refinery. The costs developed are for a mid-United States location with the methodology prepared to allow translation of costs worldwide. Also, costs for environmental and alternative unit processes are identified.

17. Document Analysis a. Descriptors

Mineral data analysis
Alumina
Bauxite
Aluminum
Alumina refinery capital and operating costs

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group Alumina

18. Availability Statement

Release unlimited by NTIS.

19. Security Class (This Report) Unclassified

20. Security Class (This Page) Unclassified

21. No. of Pages 168

22. Price $16.95

(See ANSI-Z39.18) *See Instructions on Reverse*

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

FOREWORD

This report was prepared by Raymond Kaiser Engineers Inc., a subsidiary of Raymond International Inc. in Oakland, California under U.S. Bureau of Mines Contract No J0245003. The contract was initiated under the Minerals Availability Program. It was administered under the technical direction of the U.S. Bureau of Mines with Jim F. Lemons, Jr., acting as Technical Project Supervisor. Darlene Wilson was the Contract Administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period July 17, 1984 through February 1986 and was submitted in February 1986.

This report contains no patentable features and no proprietary information appears herein.

CONTENTS

	Page
1. INTRODUCTION	17
1.1. Background	17
1.2. Purpose of the Alumina Handbook Estimating System	17
1.3. Use of the Handbook	17
1.4. Acknowledgements	17
2. THE APPLICATION OF THE ALUMINA HANDBOOK TO THE INDUSTRY	18
2.1. The Alumina Industry: Current Trends	18
2.1.1. Worldwide Production and Technology Profiles	19
2.1.2. Worldwide Consumption	25
2.2. The Alumina Handbook Estimating System	25
2.3. Capital Cost Estimating	30
2.4. Operating Cost Estimating	32
2.5. Worldwide Environmental Control Standards	33
2.5.1. Emission Control Standards - Alumina/Aluminum	33
2.5.1.1. Particulate Standards	35
2.5.1.2. Fluoride Standards	35
2.5.1.3. Opacity Standards	36
2.5.2. Emission Control Standards - Steam Plant	36
2.5.2.1. Particulate Standards	38
2.5.2.2. Sulfur Dioxide Standards	38
2.5.2.3. Nitrous Oxide (NO_x) Standards	38
2.5.2.4. Opacity	39
2.5.3. Wastewater Control Standards	39
2.5.3.1. Standards in the United States	40

CONTENTS (Cont.)

Page

2.5.3.2. Discussion for Other Countries..... 40

2.5.4. Noise Standards..... 41

2.5.4.1. Standards in the United States..... 41

2.5.4.2. Discussion for Other Countries..... 42

2.6. Worldwide LocationsCalculation Methodology..... 42

3. CAPITAL COSTS CALCULATION..... 43

3.1. Refining Unit Process Area Costs..... 47

3.1.1. Bauxite Slurry Preparation and Digestion..... 48

3.1.1.1. Bauxite Storage and Reclaim..... 48

3.1.1.2. Bauxite Grinding..... 49

3.1.1.3. Digestion..... 49

3.1.1.4. Caustic Handling and Storage..... 51

3.1.1.5. Capital Costs Calculation..... 52

3.1.2. Clarification and Mud Washing, Filtration..... 54

3.1.2.1. Clarification and Mud Washing..... 54

3.1.2.2. Filter Press..... 55

3.1.2.3. Red Mud Filtration..... 55

3.1.2.4. Red Mud Disposal..... 56

3.1.2.5. Lime Slaking and Storage..... 56

3.1.2.6. Acid Handling and Storage..... 57

3.1.2.7. Settling Aids..... 57

3.1.2.8. Capital Costs Calculation..... 58

3.1.3. Heat Interchange, Precipitation, Hydrate Classification and Evaporation..... 60

3.1.3.1. Heat Interchange..... 60

3.1.3.2. Precipitation..... 60

CONTENTS (Cont.)

	Page
3.1.3.3 Hydrate Classification	61
3.1.3.4. Evaporation Unit	61
3.1.3.5. Capital Costs Calculation	62
3.1.4. Calcination and Alumina Storage	66
3.1.4.1. Hydrate Filtration and Calcination	66
3.1.4.2. Alumina Storage and Reclaim	67
3.1.4.3. Capital Costs Calculation	67
3.1.5. Alternative Unit Processes	70
3.1.5.1. Lime plant	70
3.1.5.2. Organic Removal	72
3.1.5.3. Capital Costs Calculation	72
3.2. General Facility Costs	74
3.2.1. General Plant	74
3.2.1.1. Site	74
3.2.1.2. Compressed Air	74
3.2.1.3. Fuel Oil Storage and Distribution	74
3.2.1.4. Diesel Fuel Storage and Distribution	75
3.2.1.5. Sanitation System	75
3.2.1.6. Primary Water Plant and Storage	75
3.2.1.7. Capital Costs Calculation	76
3.2.2. Power Supply System	78
3.2.2.1. Power Plant	78
3.2.2.2. Electrical Distribution System	79
3.2.2.3. Yard Lighting	79
3.2.2.4. Communications System	80

CONTENTS (Cont.)

	Page
3.2.2.5. Capital Costs Calculation	80
3.2.3. Materials Handling	82
3.2.3.1. Wharf	82
3.2.3.2. Coal Handling	82
3.2.3.3. Capital Costs Calculation	82
3.2.4. Administration Building/Services	84
3.2.4.1. Administration Building and Laboratory	84
3.2.4.2. Personnel Services Buildings	84
3.2.4.3. Area Control Rooms and Maintenance Offices	84
3.2.4.4. Capital Costs Calculation	85
3.2.5. Services Buildings	88
3.2.5.1. Maintenance Facilities	88
3.2.5.2. Warehouses	88
3.2.5.3. Capital Costs Calculation	88
3.3. Environmental Control Systems Direct Costs	90
3.3.1. Refinery Control Systems	90
3.3.1.1. Bauxite Slurry Preparation	90
3.3.1.2. Clarification and Mud Washing	92
3.3.1.3. Calcination and Alumina Storage	96
3.3.1.4. Starch and Lime Plant Areas	98
3.3.2. General Facility Control Systems	100
3.3.2.1. Power Plant	100
3.3.2.2. Noise Control	102
3.3.3. Environmental Control Systems Cost Adjustment	103
3.4. Capital Costs Calculation - United States Location	107

CONTENTS (Cont.)

	Page
3.4.1. Direct Construction Costs	107
3.4.1.1. Transport Costs	107
3.4.1.2. Sales Tax	107
3.4.1.3. Import Duties	107
3.4.2. Indirect Costs	107
3.4.2.1. Construction Management	108
3.4.2.2. Engineering, Supervision and Procurement	108
3.4.3. Other Costs	108
3.4.3.1. Spare Parts	108
3.4.3.2. Mobile Equipment	108
3.4.3.3. Office, Shop and Laboratory Equipment	109
3.4.3.4. Startup Expenses	109
3.4.3.5. Owners Staff	110
3.4.3.6. Miscellaneous Costs	110
3.5. Translation of Capital Cost Methodology	113
3.5.1. Translation of Construction Labor Costs	115
3.5.2. Translation of Construction Materials Costs	118
3.5.3. Translation of Equipment Purchase Costs	122
3.5.4. Translation of Equipment Usage Costs	125
3.5.5. Translation of Indirect Costs	125
3.5.6. Translation of "Other" Costs	128
3.5.7. Translation of Total Plant Costs	129
4. OPERATING COSTS CALCULATION	134
4.1. Refining Unit Process Costs	134
4.1.1. Bauxite Slurry Preparation and Digestion	136

CONTENTS (Cont.)

	Page
4.1.1.1. Trihydrate Process	138
4.1.2. Clarification and Mud Washing, Filtration	140
4.1.3. Heat Exchange, Precipitation and Hydrate Classification	142
4.1.4. Calcination and Alumina Storage	144
4.2. General Facility Costs	146
4.2.1. General Plant	146
4.2.2. Power Supply System	148
4.2.3. Materials Handling	150
4.2.4. Administrative Services	152
4.3 Environmental Control Systems Operating Costs	154
4.4. Fixed and Variable Costs	156
4.5. Translation of Operating Cost Methodology	158
4.5.1. Translation of Refining Costs	159
4.5.1.1. Translation of Direct Operating Labor Costs	159
4.5.1.2. Translation of Direct Operating Energy Costs	162
4.5.1.3. Translation of Direct Operating Supplies Costs	164
4.5.2. Translation of General Facility Costs	166
4.5.3. Translation of Environmental Control Systems Costs	167
REFERENCES	169
APPENDIX A - Capital Cost Calculation Example	171
APPENDIX B - Operating Cost Calculation Example	173
APPENDIX C - Cost Updating	175

TABLES

		Page
1.	Alumina, World Production by Country	20
2.	Grouping of Unit Processes	26
3.	Worldwide Emission Control Standards	34
4.	Worldwide Emission Control Standards - Steam Plant	37
5.	Capital Cost Summary - Alumina Refinery Facility	44
6.	Air Pollution Control Technology	105
7.	Emission Control Systems Cost Factors	106
8.	Wage Rates, Productivity Factors and Construction Labor Conversion Factors - 1983	117
9.	Construction Materials Cost Factor - 1983	119
10.	Salient Data for Calculating Equipment Cost Factors	123
11.	Salient Data for Calculating Indirect Cost Factors	127
12.	Total Plant Cost Factors - 1983	131
13.	Total Plant Cost Factors - 1980	133
14.	Operating Cost Summary - Alumina Refinery Facility	135
15.	Refining - Environmental Control Systems	154
16.	Refining Operating Costs Adjustments	157
17.	Wage Rates, Productivity Factors and Operating Labor Conversion Factors	161
18.	Energy Prices and Conversion Factors - 1983	163
19.	Operating Supply Cost Conversion Factors (CCFs)	165

ILLUSTRATIONS

		Page
1.	Alumina Refining Technologies.....	21
2.	Histogram of World Alumina Refinery Capacity - 1983.....	23
3.	Alumina Refinery Logic Diagram.....	27

UNIT OF MEASURE ABBREVIATIONS

dscf	dry standard cubic feet	mg/l	milligram per liter
dsm^3	dry standard cubic meters	mt	metric tonne
gr	grain	mtpy	metric tonne per year
kg	kilogram	MWH	megawatt hour
m^3	cubic meter	sm^3	standard cubic meters
mg	milligram	ug	microgram

1. INTRODUCTION

1.1. BACKGROUND

The Minerals Availability Program (MAP) of the United States Bureau of Mines is charged with the responsibility to systematically measure and classify identified domestic and foreign mineral resources according to their respective extraction technologies, economics and commercial availability.

The MAP is therefore concerned with the costing of mineral resources as related to the current mine and mill and post-mill technologies. For this analysis, a consistent functional method of costing is a requirement. Previously, a costing procedure had been developed for preparation of feasibility type estimates for capital and operating costs of mining and primary beneficiation of various types of mineral occurrences using state-of-the-art technology. The handbook provided a costing procedure based on the summation of unit processes.

The costs were subdivided into the base components of labor, supplies, equipment, etc., with the capability of modifying the parameters so that costs could be updated by indices.

1.2. PURPOSE OF THE ALUMINA HANDBOOK ESTIMATING SYSTEM

This handbook is developed to supplement the mine and beneficiation cost estimating by providing an estimate of the 1984 post-mill costs of processing bauxite to alumina. The estimating methodology provides a subdivision of the cost components for both capital and operating costs such that costs can be translated to worldwide locations and updated with time.

The cost estimating system is based on unit processes that reflect variations in the composition of the feed material, environmental considerations and cost components on a world wide basis.

1.3. USE OF THE HANDBOOK

A knowledge of the alumina industry and processing technology is helpful to properly utilize the cost estimating system provided herein. A knowledge of the bauxite composition, and the capacity and location of the facility selected is required to obtain the desired results.

1.4. ACKNOWLEDGEMENTS

This handbook was prepared under the direction of Raymond Kaiser Engineers Inc. and for whom the responsibility of development of capital costs was assigned. AMAX Engineering and Management Services Company provided estimates of operating costs and Everest Consulting Associates provided the worldwide facility data bank and the methodology for translating costs from the United States to other locations and indexing costs at the selected locale.

2. THE APPLICATION OF THE HANDBOOK TO THE INDUSTRY

2.1. THE ALUMINA INDUSTRY: CURRENT TRENDS

In 1983, world production of alumina totalled 29,530,000 MT and exceeded 1982 production by less than 1.5 million metric tons (1). 1/ This increase marked the first year since 1980 that alumina production surpassed the production of the previous year. The startup of two new plants in Ireland and Venezuela were in part responsible for the increased output. Although greater than in 1982, 1983 production was significantly below the level of output achieved in 1980.

Of total output in 1983, approximately 95% was obtained from bauxite-the primary, and to date, the most economical raw material for the production of alumina. The remaining 5% was produced from other materials, particularly nepheline and alunite. The extraction of alumina from both types of materials is at present carried out exclusively in the Soviet Union. The use of clay in the production of alumina has attracted considerable attention in recent years and a considerable amount of research and development has been undertaken, particularly in the United States and Poland. In the latter, two pilot plants designed to recover alumina from local clays are in operation.

Of the bauxite producing nations in 1983, Ghana, Indonesia, Malaysia, Pakistan, Sierra Leone and Zimbabwe did not produce alumina domestically. Of the alumina refining countries, Canada, Czechoslavakia, East Germany, Ireland, Japan, the United Kingdom and Venezuela were totally dependent upon foreign sources of bauxite. By 1986, Venezuela, however, will be utilizing domestic bauxite from its large Los Pijiguasos deposits in Bolivar State. In the United States only one alumina plant used domestic bauxite while the remaining plants used imported bauxite from Guinea (47%), Jamaica (38%), Brazil (7%), Surinam (3%) and other countries (5%) (1).

A breakout of world alumina production by region shows Oceania as the largest producer accounting for 24.8% of total production. It is followed by Western Europe (18.6%), the Sino-Soviet block (17.7%), North America (17.2%), South and Central America (14.2%); East Asia (3.8%), Africa (1.9%) and South Asia (1.8%) (2).

Exact figures for alumina consumption are generally not available but insofar as alumina is primarily used in the production of aluminum, it is possible to approximate alumina consumption from published aluminum production data. In the International Primary Aluminum Institute (IPAI) member countries over 90% of alumina produced is consumed for metallurgical uses.(3) Typically 2-2.2 MT of alumina are required to produce 1 MT of aluminum. Other uses for alumina exist in the chemicals, ceramics, abrasives and refractories industries.

1/ Underlined members in parentheses refer to items in the list of references at the end of this report.

Price trends for alumina are virtually impossible to track owing to the vertically integrated nature of the industry. Most (an estimated 85% of alumina is traded under long-term contracts or via intra-company transfers and process are highly confidential. Only a small share (i.e., 15%) is sold on open markets (4).

According to USBM estimates, the average value for domestic calcined alumina in 1983 was $244.21. According to Bureau of the Census trade data, imported alumina had an average value of $201.25 per metric ton, f.a.s., at the port of shipment and $213.42 per metric ton, c.i.f., at United States ports (1).

In terms of the short-term outlook, the fortunes of the alumina industry are closely tied to those of aluminum. An increase in demand for the latter will certainly increase the demand and production of the former. An increase in the demand side, coupled with a reduction or no additional increase in supply, would improve the current supply-demand imbalance. However, until such developments are realized, the question of balancing one against the other will remain a critical issue facing the industry.

2.1.1. WORLDWIDE PRODUCTION AND TECHNOLOGY PROFILES

According to preliminary estimates, world alumina output in 1983 totalled 29,530,000 mt. For a breakdown of production by country see Table 1. In terms of production, Australia, the United States and the Soviet Union ranked first, second and third, respectively, and together accounted for almost half of total world output. Alumina refinery capacity for 1983, as tabulated from data collected in the World Facilities Data Base (WFDB), amounted to 41,985,000 metric tons. Thus, the capacity utilization rate was 70% during 1983.

With respect to production technology employed, Figure 1 shows that approximately 95% of alumina refinery capacity is based upon the utilization of the Bayer process. The nepheline process, used exclusively in the USSR, accounts for 3.5% of world capacity and the alunite process accounts for the 1.5% of world capacity outstanding. Other processes have been utilized in the past or are currently undergoing research and development. The Pederson process was used by the Norsk Aluminum Company refinery at Hoyanger, Norway, between 1927 and 1969. However, since the closing of the plant, the process has not been utilized--at least on a commercial basis, elsewhere. Processes which are currently under research and development and utilized on a pilot plant basis, are the Pechiney H+ (in France) and the Grzymek and Bretsznajder (in Poland) processes. Each of these are designed to extract alumina from non-bauxite materials. They are not, however, included in the capacity tabulation. (For a more detailed discussion of existing and developmental technologies, see he section titled "Refining Options" below).

TABLE 1. Alumina: world production,[1] by country[2]
(thousand metric tons)

Country[3]	1979	1980	1981	1982[p]	1983[e]
Australia	7,415	7,246	7,079	6,631	7,100
Brazil	449	493	497	606	580
Canada	953	1,202	1,208	1,127	[4]1,116
China[e]	750	750	750	800	800
Czechoslovakia[e]	100	100	100	100	100
France	1,069	1,173	1,095	960	853
German Democractic Republic	41	43	43	40	46
Germany, Federal Republic of	1,539	1,608	1,651	1,510	1,500
Greece	495	494	490	420	450
Guinea	660	708	608	549	600
Guyana[5]	200	231	170	73	--
Hungary	788	805	792	710	[4]836
India[e]	[4]493	500	500	500	450
Ireland	--	--	--	--	70
Italy	854	900	786	698	700
Jamaica	2,094	2,456	2,556	1,758	[4]1,907
Japan	1,545	1,936	1,344	959	[4]1,065
Romania[e]	502	534	540	[r]514	500
Spain	--	58	695	673	650
Surinam	1,325	1,316	1,200	1,172	1,200
Taiwan[e]	[r]113	[r]128	[r]62	[r]21	--
Turkey	70	138	131	84	[4]87
USSR[e]	2,600	2,700	2,800	3,000	3,200
United Kingdom	88	102	90	88	9-
United States[e]	6,450	6,810	5,960	4,130	[4]4,000
Venezuela	--	--	--	--	560
Yugoslavia	836	1,058	,1037	1,072	1,100
TOTAL	[r]31,429	[r]33,489	32,184	28,195	29,530

NOTES:

[e]Estimated [p]Preliminary [r]Revised

[1]Figures presented generally represent calcined alumina; exceptions are noted individually.

[2]Table includes data available through June 27, 1984.

[3]In addition to the countries listed, Austria produces alumina (fused aluminum oxide), but output is entirely for abrasives production. Output totaled 28,223 metric tons in 1973; production data subsequent to 1973 are not available.

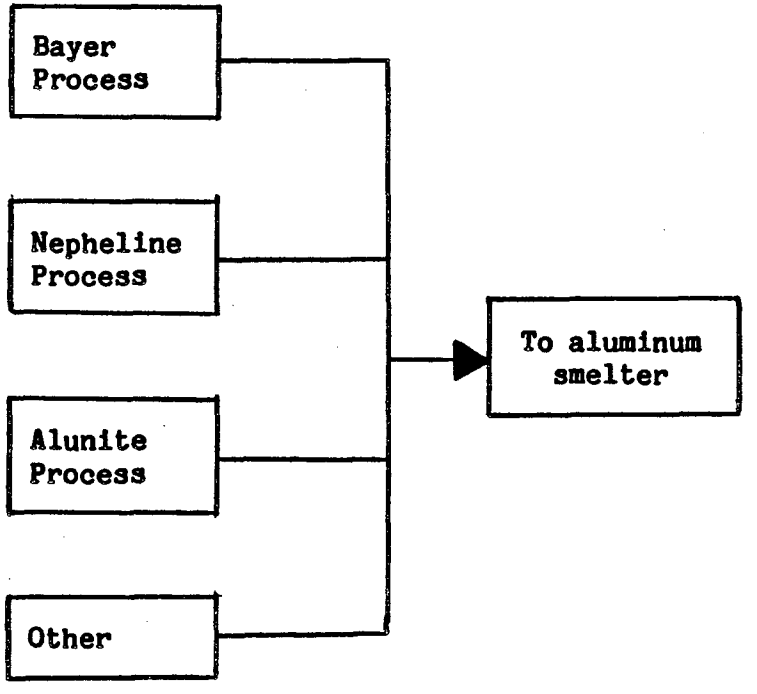
[4]Reported figure.

[5]Cancined alumina, plus calcined alumina equivalent of alumina hydrate.

SOURCE: Baumgardner, L.H. Bauxite and Alumina. Ch. in BuMines Yearbook 1983, v. 1, 12 pp.

FIGURE 1. Alumina refining technologies: shares of world and market economy country capacities

Percent of world capacity	Percent of market economy country capacity	
95.0	100.0	Bayer Process
3.5	0	Nepheline Process
1.5	0	Alunite Process
0	0	Other



The design of future plants will clearly be determined by the type and availability of feed materials to be processed. In cases where there exists a ready and/or stable access to bauxite supplies, refineries will utilize the Bayer process--perhaps with some modification, depending upon the quality of bauxite. In cases where bauxite reserves are limited and/or non-existent--as in the USSR and Poland--alternative technologies will be chosen. Another important factor that will influence the technological design of future plants is the cost of bauxite. If the cost of bauxite rises as to make alumina production from bauxite less economical than alternative sources, production from non-Bayer processes might increase. Research is currently being undertaken to determine the economic viability of these alternative technologies.

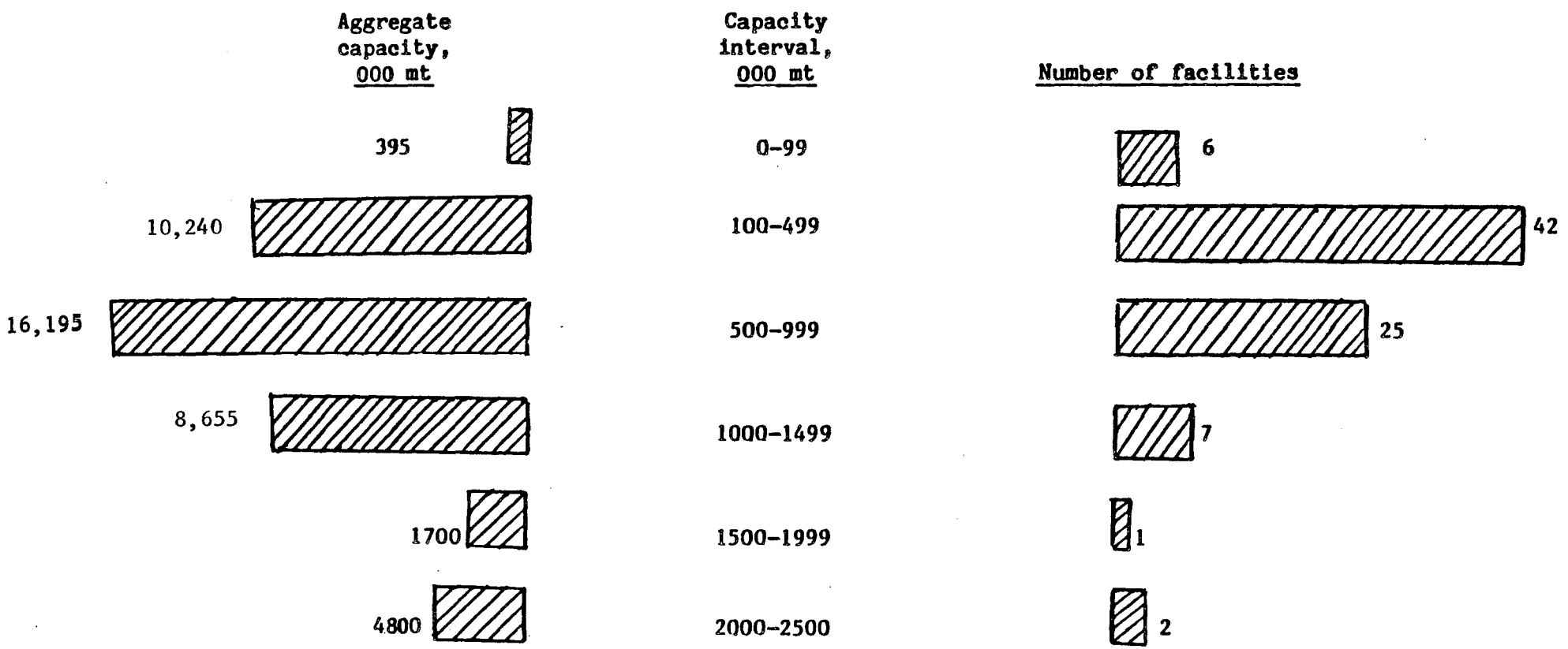
Capacity Profiles. Figure 2 provides a detailed breakdown of world alumina refining capacity by varying capacity intervals. As illustrated, the largest share of capacity, i.e., 39% or 16,195,000 metric tons, is represented by the 25 refineries operating in the capacity range of 500,000 - 999,000 metric tons. The largest number of facilities, i.e., 41, operate within the capacity range of 100,000 - 499,000 metric tons and account for nearly 24% of extant capacity. There are but three refineries with operating capacities that exceed 1.5 million metric tons. Two of them are located in Australia, the world's largest alumina producing country.

Refining Options. The technological design of future alumina refineries will be determined by the type of feed material to be processed. If bauxite is processed and the plant design incorporates the Bayer process, perhaps some modification will be required to suit the bauxite. If non-bauxite materials are processed, then alternative technologies will be employed. A brief discussion of each technology follows.

(a) Bayer Process - this process involves the grinding of bauxite and mixing with a strong solution of caustic soda. The mixture is pumped into large pressure tanks called digesters where, under direct steam heat and pressure, the alumina in the bauxite is dissolved in the caustic soda, forming a sodium aluminate solution.

The insoluble impurities remain as solids. After digestion and passing through pressure-reducing tanks, the mixture is filtered, removing the impurities in a material called "red mud" which is either discarded in a tailings pond or treated further to recover additional alumina. This recovery process, called the Alcoa combination process or the soda-sinter process, involves sintering the red mud with limestone and soda ash to recover a sodium aluminate solution which is recycled to the digesters. This soda-sinter process is used to enhance recovery at plants (in the United States and China) where lower-grade ores are processed.

FIGURE 2. Histogram of world alumina refining capacity - 1983



The alumina in solution is routed to precipitators where it is seeded with crystals of alumina trihydrate to induce precipitation. The precipitate is filtered, washed and heated in calcining kilns or fluid bed roasters to produce pure alumina. Variants on this process involve the time, pressure and temperature of the digestion. Shorter times and lower pressures and temperatures are required to digest the easily soluble gibbsite or alumina trihydrate found in many ores of North and South America (and Western Australia), leading to the description, "American Bayer Process." At the other extreme, in the European technology (called the European Bayer Process) for bauxites containing boehmite (monohydrate) which requires higher caustic concentrations and higher temperatures for digestion. For ores intermediate in composition (mixes bauxites containing principally gibbsite and minor amounts of boehmite), intermediate conditions are used in what is sometimes referred to as the "Modified American Bayer Process." Collectively, all variants are included under the Bayer Process.

(b) Nepheline Process - this process is employed exclusively in the USSR and is based upon nepheline, a sodium-potassium-aluminum silicate ($NaKAlSiO_4$ which contains generally 25-35% aluminum oxide). By some estimates, nepheline produced alumina accounts for as much as 16% of Soviet alumina production. Nepheline is processed by roasting the rock and concentrates with limestone and treating the mixture to yield anhydrous alumina, soda ash, potash and cement. Plants in the USSR using nepheline as a feedstock are located in Achinsk, Kandalaksa, Pikalevo and Volkhov.

(c) Alunite Process - this process first developed in the USSR involves crushing and grinding of alunite rock, fluid bed roasting, removal of sulfur and water leaching to recover potassium from the ore. Alumina is obtained by next applying a conventional Bayer process step. The alunite process is used at three refineries in the USSR and was estimated to account for about 2% of Soviet alumina production in 1981.

(d) Pechiney H+ Process - developed by Pechiney-Ugine-Kuhlmann (PUK) and Alcan, this process reduces coal shale, containing 20-30% alumina to ash at lower temperature. Hot sulfuric acid (H_2SO_4) is used to leach the material, then it is hydrochlorinated and the resultant aluminum chloride hexahydrate is decomposed before final calcination of the alumina. The process has been proven in a pilot plant in France, but to date no known commercial facilities are in operation that use this process.

(e) Pederson Process - (not currently in use) is a reduction process which heats bauxite, limestone, coke and iron ore in an electric furnace to produce pig iron and calcium aluminate slag containing 30 to 50% alumina. The slag is

leached by sodium carbonate solution; calcium carbonate is precipitated and a sodium aluminate solution is obtained. Alumina hydrate is then precipitated with carbon dioxide gas. Alumina hydrate is then calcined to alumina. The Norsk Aluminum facility at Hoyanger in Norway produced alumina by this process from 1928 to 1969 and some thought was given to reopening this facility in 1975.

(f) Hall-Frary Process - not in operation at any known commercial facility. This is a reduction process in which bauxite and coke are fused at high temperature. Iron, silicon, titanium oxides and some of the alumina are reduced to the metallic state and form a metallic alloy. The bulk of the alumina forms a slag which is recovered.

(g) Other - two other processes, the Bretsznajder and Grzymek process, designed to produce alumina from clay, are reportedly under consideration in Poland. Although, few reliable details of these processes are available, it is known that the former involves the hydrometallurgical extraction of alumina from clay with sulfuric acid. The second involves the grinding and mixing of clay and limestone and subsequent calcination, leaching, filtration, desilication and carbonation to produce alumina hydrate. This product is then calcined to produce alumina.

2.1.2. WORLDWIDE CONSUMPTION

Exact figures for alumina consumption are not generally published but insofar as alumina is primarily used in the production of aluminum--accounting for a steady 91% or 92% of total production since at least 1973 (3)--consumption trends can be defined on the basis of aluminum production. The remainder of alumina production is used in a number of other forms in a wide variety of applications.

Hydrated alumina is obtained directly from the Bayer process and is used extensively in water purification, the production of aluminum chemicals and in a number of industrial applications: plastics, ceramics and carpet backing. Hydrated alumina is used largely in industrial applications because of its flame retardant characteristics. Calcined alumina, although primarily used in the production of primary aluminum, has additional uses in the abrasives, ceramics and refractories industries.

2.2. THE ALUMINA HANDBOOK ESTIMATING SYSTEM

The purpose of the alumina handbook estimating system is to provide the methodology for calculating the capital and operating costs of an alumina refinery operation at any worldwide location for a range of alumina production rates.

The costs presented for both capital and operating cost have been developed from actual construction records and current available operating data. The costs have been brought forward to 1984, if from older data, by recalculation with equivalent 1984 dollars for labor, material and equipment for capital and operating costs. The process selected as a basis for the estimating system is the Bayer process.

A logic diagram, Figure 3, is provided in this section to aid in the understanding of the unit processes included in a capital and operating cost evaluation for a selected size of an alumina refinery facility. A knowledge of the analytical composition of the selected bauxite raw material, or a bauxite blend, is required to aid in the development of costs.

General analytical guidelines illustrated by the logic diagram determine the selection and costing of unit processes to allow for variations in the alumina content and the silica and organic impurity levels contained in the feed material. The estimating system divides the capital and operating costs into groups of unit processes that are required for the production of alumina and into groups of general facilities supporting the process. The groups of unit processes upon which the estimating system is developed are divided as follows:

TABLE 2

1. Bauxite Slurry Preparation and Digestion
    - o Bauxite Storage and Reclaim
    - o Bauxite Grinding
    - o Digestion
    - o Caustic Handling and Storage
2. Clarification and Mud Washing, Filtration
    - o Clarification and Mud Washing
    - o Filter Press
    - o Lime Storage and Slaking
    - o Acid Handling and Storage
    - o Settling Aids
3. Heat Interchange, Precipitation, Hydrate Classification and Evaporation
    - o Heat Interchange

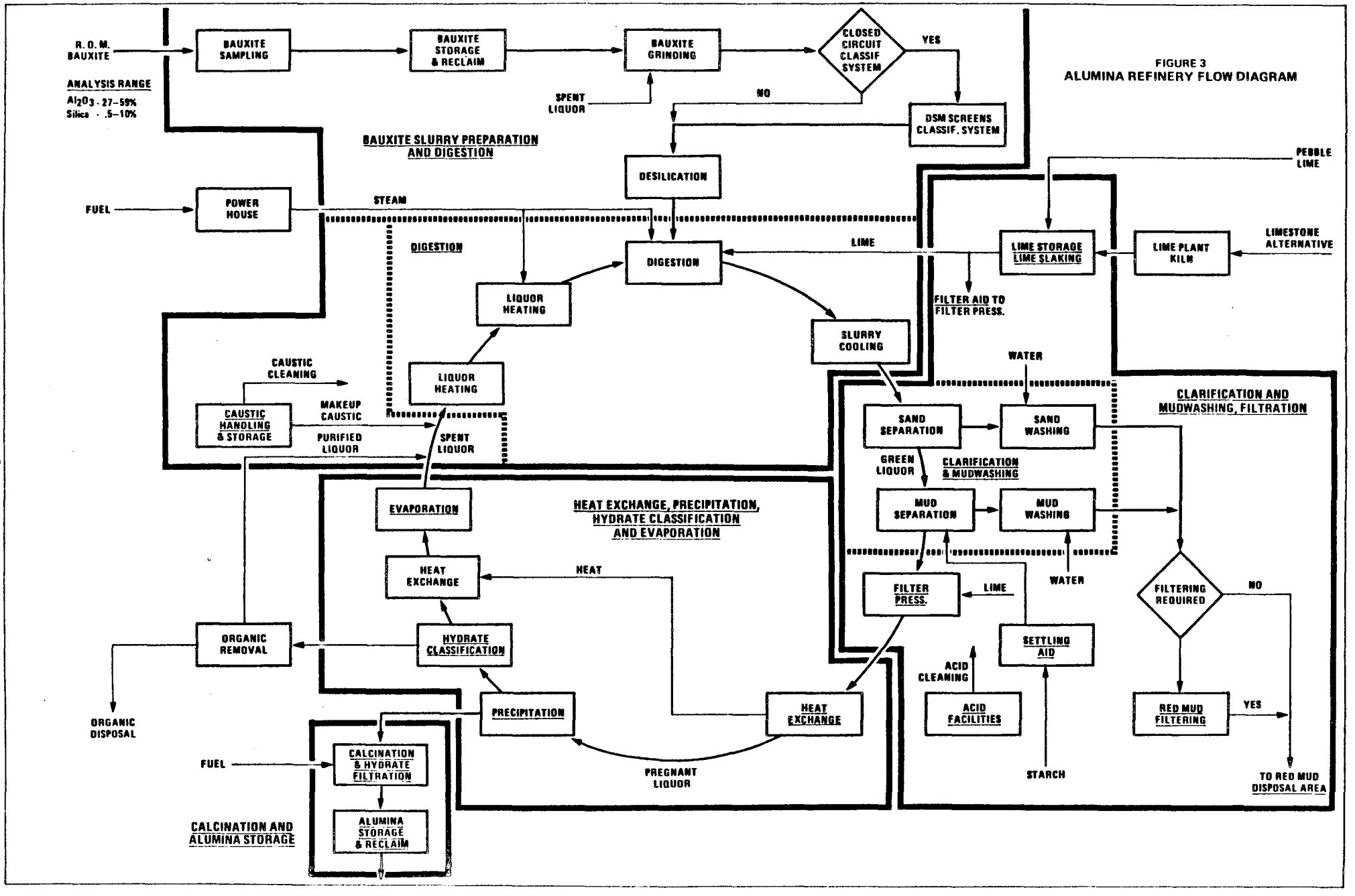


FIGURE 3
ALUMINA REFINERY FLOW DIAGRAM

- o Precipitation
- o Hydrate Classification
- o Evaporation

4. Calcination and Alumina Storage
   - o Hydrate Filtration and Calcination
   - o Alumina Storage
5. Alternative Processes
   - o Organic Removal
   - o Lime Plant

General Facilities:

1. General Plant
   - o Site
   - o Compressed Air
   - o Fuel Oil Storage and Distribution
   - o Diesel Fuel Storage and Distribution
   - o Sanitation System
   - o Primary Water Plant and Storage
2. Power Supply System
   - o Power Plant
   - o Electrical Distribution System
   - o Yard Lighting
   - o Communication System
   - o Area Control Rooms and Motor Control Centers
3. Materials Handling
   - o Port Facility
   - o Coal Handling
   - o Bauxite Handling

4. Administration Buildings and Services

- o Administration Building and Laboratory
- o Personnel Services Building

5. Services Buildings

- o Maintenance Facilities
- o Warehouses

Capital costs for alumina refineries ranging in capacity from 500,000 to 2,000,000 metric tons per year of alumina are detailed in Section 3. The costs for each group, as described previously, are presented by formula and graphic curve on a log scale.

The Bauxite Slurry Preparation and Digestion areas costs are estimated on the basis of the amount of bauxite feed material processed and the selection of high temperature digestion versus low temperature digestion. An adjustment is provided in the cost if required. Open or closed circuit crushing is a matter of preference with the matter of costs, advantages and disadvantages discussed thoroughly in the literature. This system assumes an open circuit grinding system.

The Clarification and Mud Washing, Filtration area is developed on a cost basis of the quantity of bauxite processed annually. The Heat Interchange, Precipitation and Hydrate Classification and Evaporation area and the Calcination and Alumina Storage area are cost estimated on the basis of alumina produced per year. All General Facilities costs are estimated on the basis of the tons of alumina produced per year.

The location of a facility is also a cost variable. This estimating system includes factors to adjust the components of both capital and operating costs of the United States based plant for an alternative location.

Environmental costs are included in the base cost to meet United States federal regulations. Regulatory requirements and standards are discussed on a worldwide basis in Section 2.5 and the specific environmental systems for the United States plant are estimated for capital cost in Section 3.3 and for operating costs in Section 4.3. A method is provided to adjust or remove systems as necessary to meet a particular environmental standard.

Operating costs for alumina refineries ranging in capacity from 500,000 to 2,000,000 metric tons per year of alumina are detailed in Section 4.0. The costs are also presented in groups of unit processes by formula and graph on a log scale. The division of the alumina refinery into operating cost groupings of unit processes is identical to that for capital costs.

2.3. CAPITAL COST ESTIMATING

Capital cost estimates were prepared in January 1984 dollars for alumina refineries at three production levels - 500,000, 1,000,000 and 2,000,000 mtpy. A flat, sparsely treed site at a central United States location adjacent to the lower Mississippi River (e.g., accessible by ocean going ships) was assumed for the estimates.

The estimates for direct construction costs include the following facilities:

- All process facilities
- Ancillary buildings
- Water supply
- Rail & road systems within the plant area
- Water treatment
- Disposal ponds.

Excluded are:

- Land purchase
- Incoming power line
- Rail and road systems outside the plant area
- Communications outside the plant area

Other costs, added to the direct construction cost, include:

- Sales taxes and freight
- Construction management
- Engineering, supervision & procurement
- Spare parts
- Mobile equipment
- Ancillary buildings furniture and equipment
- Startup expenses
- Owner staff during engineering, procurement and construction
- Miscellaneous costs

Miscellaneous costs include:

- Marketing studies
- Site selection
- Borehole testing
- Soils surveys
- Water supply studies and testing
- Environmental impact reports
- Process testing
- Feasibility studies

Three main sources of information were used in preparing the estimates:

- The actual material quantities and manhours used to construct a 1,000,000 mtpy refinery

- Highly detailed estimated material quantities for a 600,000 mtpy alumina refinery study.

Material quantities were input to a "standard detail" estimating system. Standard details define the manhours required, labor cost, equipment usage cost and material cost for unit quantities of each item in January 1984 dollars and are built-up from available information on crew sizes, labor rates, productivity, construction equipment required and material cost.

In a few cases, where quantities were not readily available, actual recorded manhours were used to back-calculate quantities from the standard details. If neither quantities or manhours were available, indice update of actual dollars was used; but this applied to less than 5% of the dollar amount of the estimates and the inherent minor inaccuracy is considered to be well within the overall ±25% accuracy required.

Most of the detailed estimate summaries are formatted as follows:

	Man-hours	Labor	Equip Usage	Material	Purchase	Equip Total
Earthwork						
Concrete						
Architectural						
Equipment						
Piping						
Electrical						
Total						

Each estimate summary for the base-cases of 600,000 and 1,000,000 mtpy plants are supported by detailed estimates. The estimates for the 2,000,000 mtpy plants were prepared from:

- Sketches of the facilities modifying the base-case plants
- Equipment costs
- Costs developed from key plant design criteria at different capacities.

Labor rates included in the standard details ranged from a low of $11.00 per hour in base wages for a general laborer to a high of $25.00 per hour for a general pipefitter foreman. The average labor rate for the alumina facility construction cost is $32.21. Included in the wage is burden and contractors' field overhead. Burden includes fringe benefits such as health and welfare, pension, vacation and other costs. Also included are statutory costs such as workers' compensation, unemployment insurance, social security, contractors' risk and liability insurance. Contractors' field indirect costs include general overhead, field office, tools, plant and fee. The average rates for total direct construction labor costs are divided as follows on an hourly basis for a United States alumina facility.

	Hourly Rate
Base Wage	$14.91
Burden	
Fringes (37% of base wage)	5.52
Statutory Costs (23% of base wage)	3.43
Subtotal	$23.86
Indirect Costs (35% of wages plus burden)	8.35
Total Hourly Cost	$32.21

Equipment installation costs were prorated from actual installed equipment costs.

2.4. OPERATING COST ESTIMATING

Included in the estimating section is operating cost information, equations and graphic presentations which allow the user to calculate direct operating costs for unit process group and for certain unit processes.

The labor component of the operating cost includes all direct expenses for operating and maintenance labor. A separate allowance for supervision must be made once the costs for all relevant unit processes have been assembled.

The average cost per worker has been taken as $36,500 per year. This is based on a worker actually working 1,900 hours per year at an average cost to his employer of $18.50 per hour. The hourly cost per worker consists of $11.80 in base pay and 6.70 in fringes. Included in fringes are:

- Statutory benefits - F.I.C.A., workers' compensation insurance and unemployment insurance.
- Wage-related fringes such as routine pay, shift differentials and premiums, vacation pay, holiday pay, and pay for time off for injuries, death in the family, jury duty, grievance meetings, safety meetings, lunch, etc.
- Indirect benefits such as safety shoes, pension, medical insurance and group life and accident insurance.

Supplies include all operating and maintenance supplies at costs prevailing in early 1984 in the central United States.

The energy component of the operating cost consists of all fossil fuels and related items. Typical unit costs used are as follows:

- o No. 6 fuel oil - $26.35 per barrel

The basis for costing unit processes was engineered estimates of a mid-United States plant. For each unit process grouping, the costs are based on an alumina production variable.

2.5. WORLDWIDE ENVIRONMENTAL CONTROL STANDARDS

2.5.1. EMISSION CONTROL STANDARDS - ALUMINA/ALUMINUM

Major producer countries for alumina and aluminum are identified in this section and divided into four groups according to geographical location, economic and industrial capability and identified emission control standards for each country. The North American countries, including the United States, Canada and Japan are included in Group I. Scandinavian and European countries make up Group II and Group III consists of South American and Latin American countries. African and Asian countries are in Group IV.

The worldwide environmental standards for the four groups of countries are presented in Table 3.

TABLE NO. 3

WORLDWIDE EMISSION CONTROL STANDARDS

ALUMINA/ALUMINUM

Group of Countries	Particulates	Fluoride	Opacity
Group I			
U.S.A., Canada, Japan	50 mg/m^3 .022 gr/dscf	1.9 lb/ton Al. (Potroom) 0.1 lb/ton Anode	10% Potroom 20% Anode Bake
Group II			
Europe, Scandinavia, Australia, New Zealand, Taiwan	100 mg/m^3 .04 gr/scf	50 mg/m^3 .022 gr/scf	Ringelmann II
Group III			
Brazil, Mexico, Venezuela, Argentina, Guayana, Jamaica	150 mg/m^3 .07 gr/scf	50 mg/m^3 .022 gr/scf	Ringelmann III
Group IV			
Ghana, Guinea, Egypt Turkey, Bahrain, Algeria, Indonesia, India, Surinam	300 mg/m^3 0.13 gr/scf	100 mg/m^3 0.044 gr/scf	Ringelmann III & IV

2.5.1.1. PARTICULATE STANDARDS

The emission standard of 50 mg/dsm^3 (50 milligrams per dry standard cubic meter) or .022 grains per dry standard feet is enforced by United States federal regulations for alumina handling operations. For aluminum plant potroom exhaust, there is an opacity requirement as noted in the table. Both of the United States federal standards were used for Group I countries. Japan has an emission standard of 100 mg/m^3, equivalent to .04 gr/scf for reaction furnaces, which is applicable to alumina and aluminum processes. Japan is included in Group I countries since the fluoride emission limit of 1.0 mg/m^3 in aluminum reduction gases, enforced in Japan, is far more stringent than Group II countries.

The particulate emission standard of 100 mg/m^3 (.04 gr/scf) enforced in West Germany for alumina calcining and primary reduction was used for the Group II countries. Britain has an emission standard of .05 gr/ft^3 for aluminum smelters. New Zealand has a particulate emission standard of 100 mg/m^3 for all ferrous and nonferrous processes.

The particulate emission limit was not identified for any of the Group III countries; however, Mexico has regulations that require 80% particulate emission control for smelting furnace gases. The dust loading for aluminum smelter gases has been estimated at 0.3 gr/scf. Based on this dust loading and 80% particulate removal efficiency, the dust loading in the discharge gas has been calculated at 150 mg/m^3 (.07 gr/scf.) This particulate emission limit was assumed for the other countries in Group III.

The particulate emission limit of 300 mg/m^3 (.13 gr/scf) for Group IV countries was a standard taken from the emission guidelines provided by the State of Bahrain for an aluminum rolling mill.

2.5.1.2. FLUORIDE STANDARDS

The total fluoride emission standards for Group I countries are essentially the United States federal standards for the aluminum industry.

West Germany and Australia have the same fluoride emission standard which is 50 mg/m^3 (.022 gr/scf) in the exhaust gases. This standard was assumed for the other countries in Group II. As there was no fluoride standard identified for any of the Group III countries and the standard in Australia and West Germany is less stringent than in the United States, the same standard was assumed for the Group III countries.

The limitation of total fluoride of 100 mg/m^3 in the discharged gases has been adopted by Singapore and was considered representative for the Group IV countries (6). No other regulation for fluoride control was identified in any of the group countries.

2.5.1.3. OPACITY STANDARDS

An opacity of 20% for Group I countries is the standard enforced by United States federal regulation.

Britain has an opacity standard of Ringelmann II for the exhaust gas from a stationary source and was considered as representative for the Group II countries.

Ringelmann III standard for exhaust gases has been adopted by Columbia and was considered representative for the other countries in Group III.

The opacity standards of Ringelmann III and Ringelmann IV adopted by the Philippines and Guam, respectively, were considered as being representative standards for Group IV countries.

2.5.2. EMISSION CONTROL STANDARDS - STEAM PLANT

The steam boilers, usually considered an offsite facility, is a possible source of air pollution in the alumina industries. The major pollutants of boiler exhaust are particulates, sulfur dioxide and nitrous oxides.

To evaluate the worldwide boiler emission standards, major producers of alumina and aluminum are identified and divided into four groups of countries.

The North American countries such as the United States and Canada are included in Group I. The Scandinavian and European countries are included in Group II. Group III consists of South American and Latin American countries. African and Asian countries are included in Group IV.

Further evaluation was then made regarding the economic situation, industrial capability, and existing air quality standards, if any, of each country to justify the location of the country in a particular group. As a result of this evaluation, Japan is included in Group I countries, and Australia and New Zealand are included in Group II.

The emission standards for boiler exhaust in the different countries are summarized in Table No. 4.

Table No. 4

WORLDWIDE EMISSION CONTROL STANDARDS - STEAM PLANT

Countries by Group	Particulates		Sulfur Dioxide		Opacity	Nitrous Oxide	
	Oil-fired	Coal-fired	Oil-fired	Coal-fired		Oil-fired	Coal-fired
Group I USA, Canada, Japan	0.1 lb/10^6 Btu	0.1 lb/10^6 Btu	0.8 lb/10^6 Btu	1.2 lb/10^6 Btu	20%	0.3 lb/10^6 Btu	0.7 lb/10^6 Btu
Group II Europe, Scandinavia, Australia, New Zealand	0.45 lb/10^6Btu	300 mg/m^3	1.22 lb/10^6 Btu (20 kg/t fuel)	2400 mg/m^3	Ringelmann II	300 mg/m^3	300 mg/m^3
Group III Brazil, Mexico, Peru, Bolivia, Argentina, Venezuela, Jamaica, Guayana	0.55 lb/10^6Btu (1 kg/10^6 Kcal)	0.55 lb/10^6Btu (1 kg/10^6 Kcal)	3.9 lb/10^6 Btu	6.4 lb/10^6 Btu	Ringelmann III	0.62 lb/10^6Btu	0.8 lb/10^6 Btu
Group IV Ghana, Zambia, Morocco, Zaire, Guinea, Egypt, Turkey, India, Burma, Malaysia, Thailand, Indonesia	900 mg/m^3	900 mg/m^3	3.9 lb/10^6 Btu	6.4 lb/10^6 Btu	Ringelmann III & IV	2000 mg/m^3	2000 mg/m^3

2.5.2.1. PARTICULATE STANDARDS

The particulate emission standard of 0.1 $lb/10^6$ Btu for oil and coal-fired boilers, as indicated for Group I countries, is essentially a new source performance standard presently enforced by United States regulations. The particulate emission standard of 200 mg/m^3 adopted by Japan is only slightly higher than the United States standard.

The particulate emission standards of 0.45 $lb/10^6$ Btu and 300 mg/m^3 for oil and coal-fired boilers, respectively, adopted by Denmark and West Germany are taken as representative for Group II countries.

The particulate discharge standard for boilers of 1.0 $kg/10^6$ Kcal adopted by Mexico was considered representative for Group III countries.

The particulate emission standard of 900 mg/m^3 adopted by the Philippines for all stationary sources was taken as representative for coal-fired and oil-fired boilers in the Group IV countries.

2.5.2.2. SULFUR DIOXIDE STANDARDS

The sulfur dioxide emission limits of 0.8 $lb/10^6$ Btu for coal-fired boilers are the standards enforced by United States federal regulations and considered representative of Group I countries.

The sulfur dioxide emission standard of 20 kg/ton of oil for oil-fired boilers adopted by Sweden and 2,400 mg/m^3 for coal-fired boilers adopted by Spain were taken as representative of the Group II countries.

The sulfur dioxide emission standard was not identified for any of the Group III and Group IV countries. However, Greece and Portugal have regulations that limit the use of heavy fuel oil and coal containing more than 3.5% and 4% of sulfur by weight, respectively. This sulfur content translates to a sulfur dioxide emission standard of 3.9 $lb/10^6$ Btu for coal-fired boilers. These emission values are considered representative of the Group III and Group IV countries, based on similarities in economic and industrial development.

2.5.2.3. NITROUS OXIDES (NO_x) STANDARDS

The nitrous oxide standards of 0.3 $lb/10^6$ Btu for oil-fired and 0.7 $lb/10^6$ Btu for coal-fired boilers for Group I countries are the new source performance standards presently enforced by United States federal regulations. The nitrous oxide emission standard of 180 ppm in exhaust gases adopted by Japan is comparable with the United States standard of 0.3 $lb/10^6$ Btu for oil-fired boilers.

Spain has a nitrous oxide emission standard of 300 mg/m^3 in the exhaust gases. This standard is considered representative of Group II countries (6).

There are no nitrous oxide standards identified for any of the Group III countries. Environmental guidelines by the World Bank identifies staged combustion as one of the acceptable technologies to reduce nitrous oxide by 20 to 40% in the boiler exhaust gases. Assuming 20% nitrous oxide removal from the exhaust, the nitrous oxide emission in the exhaust was calculated as 0.62 lb for oil and 0.8 $lb/10^6$ for coal-fired boilers. These values are selected as an emission standard for the Group III countries.

Singapore has a standard of 2,000 mg/m^3 for nitrous oxide discharge in the exhaust gas from all stationary sources. As there are no nitrous oxide standards identified for any of the Group IV countries, Singapore was considered representative of the Group IV countries.

2.5.2.4. OPACITY

An opacity of 20% for Group I countries is the standard enforced by United States federal regulation.

Britain has an opacity standard of Ringelmann II for the exhaust gas from a stationary source and was considered as representative for the Group II countries.

Ringelmann III standard for exhaust gases has been adopted by Columbia and was considered representative for other countries in Group III.

The opacity standards of Ringelmann III and Ringelmann IV adopted by the Philippines and Guam, respectively are considered representative standards for Group IV countries.

2.5.3. WASTEWATER CONTROL STANDARDS

Wastewater containing heavy metals are common to the nonferrous metals industry. Worldwide health organizations universally agree that these constituents are toxic to animal and human life, even in concentrations at the detectable limits of state-of-the-art analyzers. Where possible, wastewater streams should be recycled, especially, in plants constructed in water-short areas. Additionally, dry versus wet scrubbers should be employed to reduce wastewater flow volume which would otherwise require treatment prior to discharge.

Many of the companies producing alumina and aluminum are located in countries commonly referred to as Less Developed Countries (LDC's). Standards for wastewater discharges from such industries are scant and in many cases are imposed externally in the form of requirements for construction loans from such organi-

zations as the World Bank. The following standards for nonferrous metals industrial wastewater discharge for countries outside the United States is derived principally from such recommended criteria.

2.5.3.1. STANDARDS IN THE UNITED STATES

The United States standards for wastewater discharges for new sources are:

- o Bauxite Refining:

  There shall be no discharge of process wastewater pollutants to navigable waters.

- o Primary Aluminum Smelting:

Effluent Characteristic	Maximum for any one day	Average of daily values for 30 consecutive days shall not exceed
	(kg/100 kg of product)	
Fluoride	0.05	0.025
Total Suspended Solids	0.1	0.05
pH	Within the range of 6.0 to 9.0.	

2.5.3.2. DISCUSSION FOR OTHER COUNTRIES

In general, most countries outside the United States have adopted a policy for wastewater discharge based on a "site specific" evaluation of the environment in the vicinity of the nonferrous metals smelting and/or refining plant. The United Kingdom, for example, "... sees little justification for (pollution control) systems based on fixed concentrations of pollutants in effluents regardless of the nature and use of the receiving body in which the effluent flows."

The State of Bahrain, considered to be a growth emerging country in terms of industrial development, has adopted the following standards for nonferrous metals' wastewater discharges to the sea.

	Allowable Discharge to the Sea, mg/l
Total Suspended Solids	200
Chemical Oxygen Demand	160

Aluminum	10
Copper	1
Lead	1
Zinc	10
pH	6.0 to 9.0

The World Bank as an integral part of its appraisal and supervisory function is required to evaluate the adequacy and effectiveness of pollution control measures for projects involving industrial operation. The Office of Environmental Affairs within the World Bank has developed guidelines covering wastewater discharges for industries encountered in the Bank lending programs. The following guidelines have been prepared for the nonferrous metals industries, and are are used for the Group III and Group IV countries.

- o Bauxite

  There is to be no disposal of red mud into either the waterways or into the sea.

- o Aluminum

	Max. 24-hr kg/mt of product
Fluorides	0.4
Total Suspended Solids	0.10
pH	6.0 to 9.0 units

2.5.4. NOISE STANDARDS

Noise standards are generally applicable to every industry and applied to all the process and material handling areas.

2.5.4.1. STANDARDS IN THE UNITED STATES

The OSHA (Occupational Safety and Health Administration) of the United States permits eight hours per day exposure to noise levels of 90 dBa. The exposure time limit is halved for each 5 dBa increase up to the maximum permitted continuous noise level of 115 dBa.

Community noise codes are generally based on annoyance and sleep interference. Permitted levels for noise that intrudes on residential properties are much lower than permitted levels within the plants. The various industrial and city standards in the United States generally allows continuous noise levels to be between 60 and 65 dBa during the day time and 50 to 55 dBa during night time, due to industrial operation. These standards are considered to be representative for the Group I countries.

2.5.4.2. DISCUSSION FOR OTHER COUNTRIES

Continuous equipment noise exposure (8 hours per day) to a level above 90 dBa will substantially increase the risk of developing a hearing handicap. The OSHA exposure level indicated above is generally accepted for an industrial facility built anywhere in the world.

Allowable community noise levels indicated depends largely on the residential activities and type of community such as rural and urban. In some communities a sound barrier may be required to surround an adjacent plant. This would apply to Group I and Group II industrialized countries.

However, for most of the third world countries of Group III and Group IV, a sound barrier surrounding the process units may not be required as the resultant overall noise level would not be as high as that in industrialized countries.

2.6. WORLDWIDE LOCATIONS CALCULATION METHODOLOGY

The basic method for estimating both capital and operating costs at foreign location, given cost estimates for an equivalent United States facility is through a series of cost conversion factors (CCFs). CCFs are defined as the ratio of the cost (expressed in $US) in the country of interest to that in the United States and are derived by comparing prices of similar goods and services at the foreign locations with those in the United States. Since all costs are being compared with United States costs, the CCF for the United States is unity by definition.

In terms of capital costs, CCFs are calculated for six component cost categories: construction labor, construction materials, equipment, equipment usage, indirect costs and "other" costs. In addition, a total plant factor (calculated as the appropriately weighted average of the six component CCFs mentioned above) is provided as a means for a simpler, yet less precise, method for estimating costs at foreign locations. Total plant factors assume a particular set of decision variables in the construction of the United States base-case plant. Alternative plant designs (e.g., different plant capacities and/or plant configurations) will give slightly different CCFs. In short, total plant factors are suitable for initial approximations only and should be followed-up by a more disaggregated analysis, as implied via the use of the six component CCFs already discussed.

In terms of operating costs, CCFs are calculated for labor, energy and supplies contained under the three larger categories of operating cost: alumina refining costs, general facility costs and environmental control systems costs.

For the estimation of costs abroad, operationally all that is involved is to apply the appropriate CCF to each of the component costs of the United States base-case plant. These costs are then added to produce an estimated total cost at the foreign location.

3. CAPITAL COSTS CALCULATION

The following discussion describes the sequential activities for development of capital costs for an alumina refinery facility utilizing the estimating system developed for this handbook. The calculation is for a facility located in the United States. Please refer to Section 3.5 for transferring costs elsewhere. The calculation steps are:

1. Determine the size of facility in terms of metric tons per year of alumina to be produced.

2. Select an analysis of the proposed bauxite or blend of bauxite feed material.

3. Calculate the required tons of bauxite required per year. Select an alumina recovery value based on the bauxite analysis and the expected operating conditions.

4. Select the unit processes from the logic diagram based on the bauxite analysis.

5. Refer to Section 2.5 Worldwide Environmental Control Standards and Section 3.3 Environmental Control Systems Costs and select the environmental control system. Systems to meet United States Standards are included in the unit process costs. Differences in cost for other systems are applied as described in Section 3.3.3 for sites located other than in the United States.

On completion of the steps described above, direct construction costs for each of the unit process areas are obtained from Sections 3.1 and 3.2. These costs are tabulated in Table 5 for the unit processes selected and summed for a subtotal of direct construction costs.

6. Calculate transportation costs, sales taxes and import duties and sum for Total Construction Costs.

7. Refer to the Indirect Costs Section 3.4.2 and calculate indirect costs based on direct construction costs totalled in 6. Sum for Total Facility Cost.

8. Add to the total facility cost the startup expenses, spare parts, mobile equipment, office equipment, startup expense, mechanical and miscellaneous costs.

A quick method for calculating the total project cost for a United States facility is provided by the capital cost curve at the end of this section.

TABLE 5
CAPITAL COST SUMMARY
ALUMINA FACILITY

DATA
Location _____

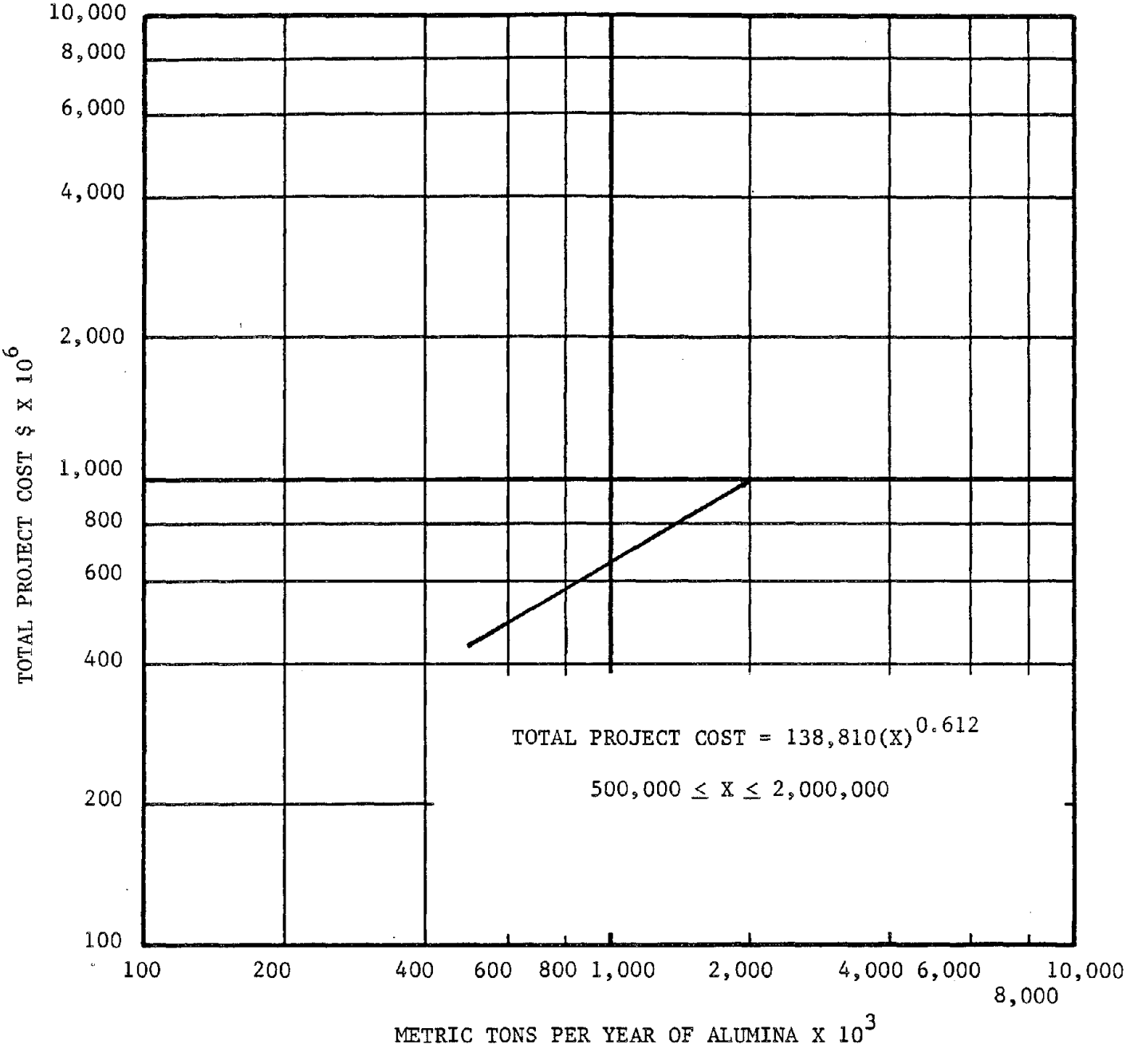
Capacity:
Alumina (mtpy) _____
Bauxite (mtpy) % Alumina _____
Recovery % Alumina _____

Country Cost Factors

Unit Process Description	Section	Labor	Materials	Equipment Usage	Equipment	Total
DIRECT CONSTRUCTION COSTS						
REFINING						
BAUXITE SLURRY PREP/DIGEST	3.1.1					
Handling/Storage/Reclaim						
Grinding						
Digestion						
Caustic Handling						
CLARIFICATION/FILTRATION	3.1.2					
Clarification/Washing						
Filter Press						
Red Mud Filter/Disposal						
Lime Slaking/Storage						
Acid Handling/Storage						
Settling Aid						
HEAT EXCHANGE/PRECIPITATE and CLASSIFICATION	3.1.3					
Heat Exchange						
Precipitation/Classification						
Evaporation						
CALCINATION/ALUMINA STG	3.1.4					
Calcination						
Alumina Handling						
OXALATE CONTROL	3.1.5.1					
LIME PLANT	3.1.5.2					
Subtotal						
GENERAL FACILITIES						
General Plant	3.2.1					
Power Supply System	3.2.2					
Material Handling	3.2.3					
Administration Buildings	3.2.4					

TABLE 5 (Cont.)
CAPITAL COST SUMMARY
ALUMINA FACILITY

Service Buildings	3.3.5					
Subtotal Direct Construction Costs						
Transport/Sales Taxes						
Export Country (6%)						
Ocean Freight (15%)						
Import Country (6%)						
Sales Taxes (%)						
Import Duty						
Subtotal						
Total Construction Costs						
INDIRECT COSTS						
Construction Management	3.4.2					
Engineering, Supervision and Procurement	3.4.2					
Subtotal						
TOTAL FACILITY COST						
OTHER COSTS						
Spare Parts (2.5%)	3.4.3.1					
Mobile Equipment	3.4.3.2					
Office Equipment	3.4.3.3					
Start Up Expenses	3.4.3.4					
Owner Staff	3.4.3.5					
Miscellaneous	3.4.3.6					
Technical						
Subtotal Other Costs						
TOTAL PROJECT COST						



3. TOTAL PROJECT COST

SCALE—LOGARITHMIC

The total plant project cost for the United States facility assumes that all unit processes described in Section 3 are utilized in the calculation of direct construction costs. Freight costs, indirect costs and other costs are included as described.

Alternative unit processes such as oxalate control and lime plant are described and costed in Section 3.1.5 should those be required for specific cases.

3.1. REFINING UNIT PROCESS AREA COSTS

This section provides the method for calculating direct construction costs for individual unit process areas selected for a specific refinery design and bauxite feed material. The costs were developed from actual projects with costs detailed by concrete, steel, architectural, equipment, piping and electrical/instrumentation categories. For each cost category detailed estimates were prepared and further subdivided by components of: actual manhours required to do the work, the cost of materials, the cost of construction equipment usage and the cost of equipment purchased.

For each unit process area described herein the total direct construction cost can be obtained from a cost curve. The cost components are subdivided as a percentage of the total direct construction cost and itemized as follows:

Labor	%
Materials	%
Equipment Usage	%
Equipment	%

The basis for labor, material and equipment costs in 1984 dollars for a facility located in the mid-United States has been discussed previously in Section 2.3.

The costs for each unit process are based on a range of alumina capacity of 500,000 to 2,000,000 metric tons per year. However, each unit process is costed according to the specific process variable which determines the size of the equipment.

The base alumina plant is a chemical plant using the Bayer process to produce alumina (Al_2O_3) from bauxite.

The bauxite is received at the plant and stored in open storage piles. During the storage operation and subsequent reclaim operation, the facilities have the capability of blending the bauxite to ensure the silica content as fed to the grinding mills is kept at acceptable levels.

Bauxite reclaimed from the storage area is fed to grinding mills via a belt conveyor system In the mills, the bauxite is mixed with caustic liquor and finely ground. The resulting bauxite slurry is pumped to the Digestion area where the liquid mixture is heated

The process liquor is pumped from the Digestion area to the Clarification and Mud Washing area where the waste mud is separated from the process liquor which carries the dissolved alumina. The waste mud is washed in a countercurrent decantation system of washers. From the last washer, it is pumped to a Red Mud Filter Facility where the mud is washed with hot condensate to reduce soda content to a minimum prior to pumping the mud to the disposal area.

The solids-free liquor (pregnant or green liquor) is pumped from the Clarification and the Mud Washing Area to the Filter Press Area where any remaining mud particles are removed. The clarified stream is pumped to the Precipitation Area via the Heat Interchange Area where waste heat is recovered by the interchange of heat between the pregnant liquor pumped to Precipitation and the cool spent liquor returning from Precipitation.

In the precipitation tanks, the pregnant liquor is seeded with fine alumina hydrate particles and agitated to precipitate the alumina hydrate from the liquor.

The alumina hydrate is concentrated by settling and is pumped to the Hydrate Filtration and Calcination Area where the water of hydration is driven off.

The alumina from the Calcination Area is delivered to calcined alumina storage silos. The storage area is equipped with an alumina load-out system.

Spent liquor from the Precipitation Area is recycled back through the Heat Interchange area and through the Evaporation Area prior to adjustment of the caustic concentration by adding additional (make-up) caustic as required.

A Steam Power Plant is included to provide both electrical energy and heating steam for the process.

Other support facilities include: a kiln for the burning of limestone to manufacture lime, if required, lime slaking and distribution system for the process and for filter aid; storage and process facilities for settling aid; storage and distribution system for acid, caustic soda and fuel oil.

3.1.1. BAUXITE SLURRY PREPARATION AND DIGESTION

3.1.1.1. BAUXITE STORAGE & RECLAIM

Incoming bauxite is fed through a Bauxite Sampling Facility. The Bauxite Sampling system consists of primary and secondary sample cutters, belt feeders, sample transfer conveyor and all necessary ancillary items. Surplus reject sample bauxite is delivered back to the bauxite stockpiles. Incoming bauxite is delivered to storage by a stacker system. Bauxite is blended into separate blending piles and

reclaimed by bucket wheel reclaimers. The bucket wheel reclaimers feed onto a conveyor system that feeds directly to the bauxite grinding facility. The conveyor systems are equipped with metal detectors, dust suppression systems and weigh scales.

3.1.1.2. BAUXITE GRINDING

The bauxite is delivered via tripper conveyors into three storage bins. Bauxite is transported from the storage bins by weigh feeders and conveyors into grinding mills. Hot spent caustic is metered into the grinding mill feed spout where it mixes with the incoming bauxite. Each grinding mill discharges via a trommel screen into a mill discharge tank which is enclosed and vented. Each mill discharge tank is equipped with two centrifugal slurry pumps which pump the bauxite slurry to surge tanks. The bauxite grinding facility is equipped with dust control equipment and feed equipment for feeding grinding media to the mills.

3.1.1.3. DIGESTION

Prior to digestion, slurry desilication is accomplished in a number of desilicator tanks, in series, designed to allow sufficient retention time for the separation of the silica to take place. The slurry stream is heated in live steam heaters prior to entering the first tank. From the last desilicator tank, the bauxite slurry is pumped to the digestion unit. The slurry may be heated in the desilication tanks also.

The desilicators are equipped with rake mechanisms to allow settled mud to be raked to the center discharge nozzle at the bottom of the desilicator. Caustic cleaning equipment is installed for cleaning the desilicators; the equipment includes a caustic cleaning heat exchanger.

The digestion unit provides facilities for the continuous extraction of alumina from the bauxite. The facility includes two or more identical equipment trains. Each train consists of a heat exchange section, digester vessel and flash tank section, feed and surge tanks, pumps, piping, relief systems and ancillaries.

Bauxite slurry is fed from the grinding section into the digester unit. Spent liquor returning from the precipitation area via the heat interchange system passes through the heat exchangers within the digestion area and, finally, into the digesters where it is mixed with bauxite slurry. The heat exchangers utilize live steam and flashed steam resulting from the cooling of the digester effluent. Each train is equipped with a digester vessel and an additional digester vessel which is included as a common spare.

The digester vessels provide a means of heating the mixture of bauxite slurry and spent liquor to a desired temperature and holding the slurry for an adequate period of time to dissolve the alumina in the bauxite. Heating of the slurry in the digester is accomplished by direct injection of steam from the power plant.

The heated slurry discharges from the digester through a series of flash tanks where pressure reduction (flashing) occurs with the slurry flashing down from digester pressure to atmospheric pressure. The vapor from the flash tank is condensed in the heat exchange section described above. The condensate from the heat exchangers, depending on its quality or degree of contamination, is either returned to the power plant and used as boiler feed water or used as process water.

The slurry from the last flash tank feeds to a blow-off tank and is then pumped to the clarification area by the digester blow-off pumps. A pressure relief system is included for pressure relief of both the digesters and the flash tanks. Caustic cleaning facilities and acid cleaning facilities are included with all pumps, piping and ancillaries.

To facilitate maintenance of the heat exchangers, flash tanks and digesters, overhead cranes and jib cranes are available. An elevator gives access to the main operating floors.

SILICA

Silica in bauxite occurs in the form of kaolinite-$Al_2Si_2O_5(OH_4)$, or quartz (SiO_2). Kaolinite in bauxite dissolves as fast as the alumina values and for this reason, is called "reactive silica", whereas, quartz remains unreactive up to approximately 240 degrees Celsius. The majority of alumina plants operate their digestion units below this temperature. The exceptions are the small number of plants that are processing diasporic bauxites, which are more difficult to digest than boehmitic bauxites.

Silica dissolved in aluminate liquor is undesirable because:

(a) It re-precipitates and deposits itself as scale on the walls of the heat exchanger transfer surfaces, as well as tankage and other equipment.

(b) Most importantly, it will contaminate the precipitation liquor and will end up in the product aluminum in values exceeding 0.22%, which is the upper limit in today's market for a saleable product.

(c) The dissolved silica immediately begins to precipitate out of solution concurrently as other silica in fresh bauxite is dissolving. In so reversing itself (which is the desirable desilication process solid, eventually reporting to the red mud circuit), it combines with valuable aluminum and sodium hydroxide values to form desilication product. Consequently, the "reactive silica" penalizes the process by consuming large quantities of expensive caustic as well as alumina values, which would otherwise report to product.

Desilication can be achieved in regular digester vessels at high temperature and pressure (where the desilication reaction takes longer retention time than the digestion of aluminum). Total retention time is based on desilication reaction.

Alternatively, desilication can be achieved over a period of 8 hours (approx.) in pre-silication vessels at atmospheric pressure and temperature of 90 degrees Celsius. The desilication product formed in this case tends to be fine and presents a settling problem. When there is a lot of desilication process, desilication is preferably accomplished in the digesters. If reactive silica in the ore is relatively low, it may be more desirable to pre-desilicate.

The free caustic can be neutralized by feeding some bauxite slurry into the spent liquor as it is pumped into the final high temperature heat exchangers. Before feeding the bauxite slurry into the spent liquor stream, it is imperative to pre-desilicate in order to prevent scaling of the heaters.

3.1.1.4. CAUSTIC HANDLING AND STORAGE

Caustic soda is consumed in the alumina process by the reaction with silica in the bauxite. Losses occur with sand rejects, with the mud slurry to the mud disposal area, at calcination and miscellaneous other points. The facility includes the unloading, storage and distribution to the various process units of a 50% caustic solution. The 50% caustic soda is received in railway tank cars and unloaded into a large storage tank. From the storage tank, the stored caustic is pumped to the following process units where the caustic is either used as make-up caustic in the spent liquor circuit, or for extensive caustic cleaning purposes (i.e., descaling of pipe, vessels, tanks and other miscellaneous equipment). The process units include the digestion unit, clarification and mud washing, precipitation, settling aid, filter press, red mud filtration, and the acid unloading and storage unit.

3.1.1.5 CAPITAL COSTS CALCULATION (DIRECT CONSTRUCTION COSTS)

The direct construction costs for the Bauxite Slurry Preparation and Digestion Areas are provided by the following cost curve for alumina plants ranging in capacity from 1,200,000 to 6,800,000 metric tons per year of bauxite consumed. The allocation of costs for informational purposes to each of the unit process areas is:

Bauxite Storage and Reclaim	14%
Bauxite Grinding	17%
Digestion	57%
Caustic Handling and Storage	12%

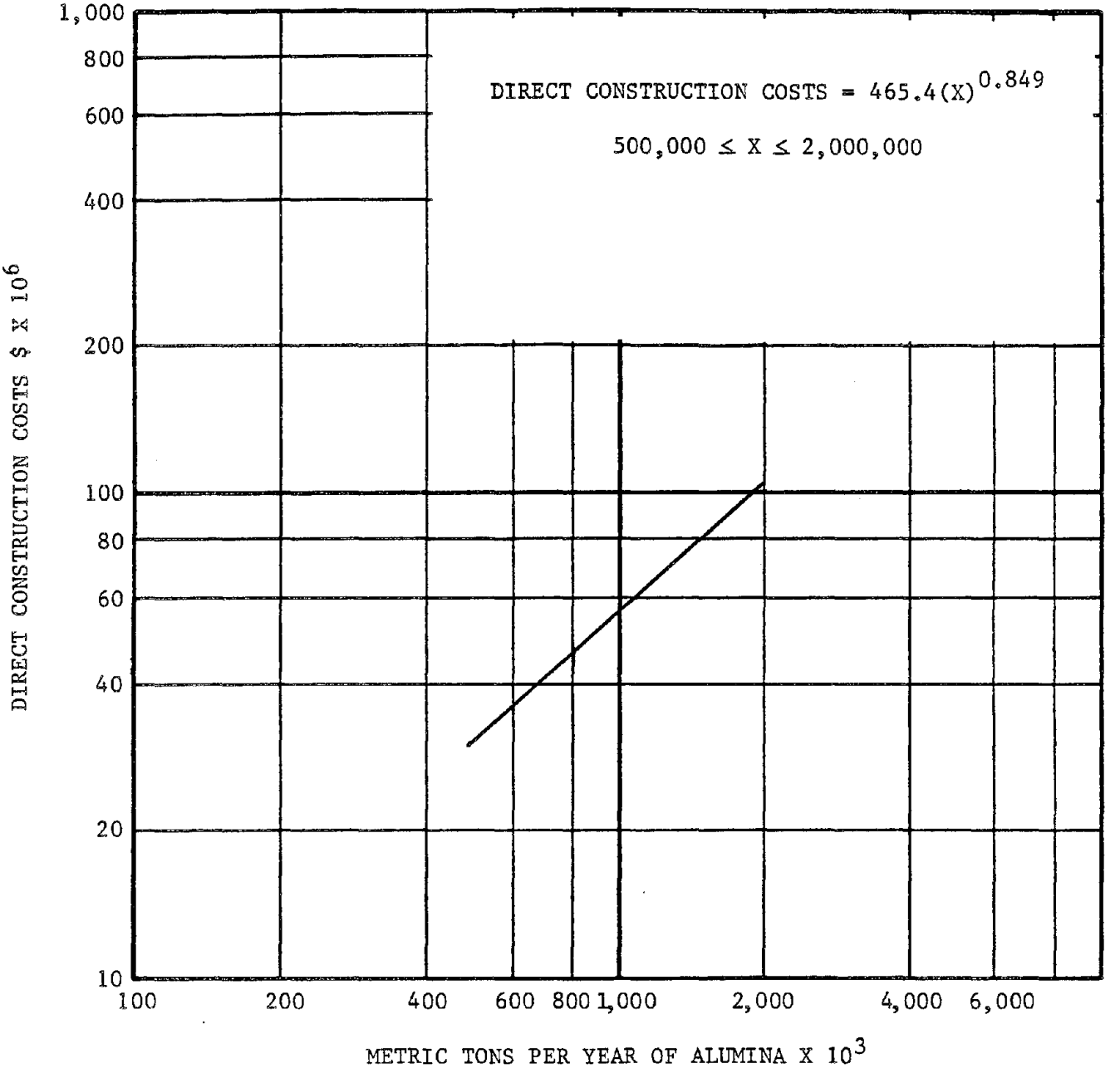
The bauxite feed material may require a higher temperature digestion than the low temperature digestion costed in this base-case for the Alumina Handbook. Should high temperature digestion be required, the capital cost for digestion calculated from the above percentages should be adjusted upward by a 1.67 multiplier.

The costs are subdivided into the following components:

Labor	32%
Material	30%
Equipment Usage	10%
Equipment	28%

The regression equation is:

$$\text{Direct Construction Costs} = 465.4(X)^{0.849}$$



3.1.1. BAUXITE SLURRY PREPARATION AND DIGESTION

SCALE—LOGARITHMIC

3.1.2. CLARIFICATION AND MUD WASHING, FILTRATION

3.1.2.1. CLARIFICATION AND MUD WASHING

The clarification and mud washing unit provides the facilities to clarify the incoming slurry being pumped from digestion by:

- Removal of coarse sand, deliquoring the sand, and washing the sand to recover caustic soda
- Separation of the mud and the liquor in settler tanks
- Washing of the mud in a countercurrent decantation system of washers to recover caustic soda
- Pumping solids relatively free of pregnant or green liquor to the filter press building for final clarification.

Settlers and washers with rake mechanisms provide consolidation of the mud and clear liquor overflows.

Bauxite slurry is delivered to the Clarification and Mud-washing Area from the digester unit. The slurry stream passes through a bank of hydroclones in parallel to remove the coarse sand. The hydroclone underflow containing the sands discharges to a classifier system. The sand is deliquored and washed to a low soda content in a series of classifiers. After washing, the sand is deliquored to 65% to 70% solids and piped to a sands disposal tank. The overflow from the hydroclones is gravity fed to two operating settlers where a small amount of flocculant (starch solution) is added to aid settling. The mud settles to the bottom of the settlers and is continuously removed as 30% solids slurry. The settler overflow is gravity fed to an overflow tank and is pumped to the filter press building for final clarification.

The mud slurry from the settler underflow is pumped continuously to the first of a series of washers with rake mechanisms. The washer system consists of two parallel trains of washers. In each system, the mud is pumped through the washers in series, while wash water is pumped countercurrent through the washers. Overflow from the first washer is returned to the digestion unit and dilutes the pregnant or green liquor reporting to the settlers. Underflow from the last washer in each train is pumped to the red mud filter unit for final washing. A spare settler/washer is included which can be used when either a settler or washer is taken out of service for cleaning, descaling or maintenance.

Additional secondary streams such as the sand classifier overflow, cloudy filtrate and filter waste from the filter press unit, and hose water are included, but not covered in this description.

3.1.2.2. FILTER PRESS

The filter press unit provides the facilities for reducing the amount of solids that remain in the pregnant or green liquor overflow from the settlers in the clarification and mud washing unit.

Settler overflow from the clarification area, with filter aid added, is pumped through filter presses, in parallel, to remove the remaining solids in the pregnant liquor. The clear filtrate reports to a clear filtrate tank for pumping to the precipitation unit via the heat interchange unit. Cloudy filtrate is diverted to a cloudy filtrate tank and returned to the clarification area. The filtered press cake is discharged to a press cake tank via a vibratory screen to facilitate removal of scale and miscellaneous lump material. The press cake is pumped to the clarification area for washing and recycle of liquor back through the filters.

A caustic cleaning system, with heat exchanger pumps and piping, is provided as is an acid cleaning system with a separate tank for acid cleaning of the leaves.

3.1.2.3. RED MUD FILTRATION

Underflow from the last stage of washing in the Clarification and Mud Washing Area is pumped to the red mud filtration unit where the red mud is filtered and washed on rotary drum filters to recover dissolved alumina and soda. The mud filtration system is designed for continuous 24 hour per day operation with sufficient filters installed to allow for scheduled filter cleaning, cloth changing and maintenance without interrupting process flows.

Slurry underflow from the last washing stage in the Clarification and Mud Washing unit is pumped to a number of variable speed rotary drum filters operating in parallel. The slurry is filtered and the red mud cake is washed during the filtering operation to recover dissolved soda and alumina. The red mud cake is washed on the filter drums with hot condensate. The washed cake, at approximately 60% solids, is discharged from the filters via a roller discharge system into a trough type agitator or repulper.

Variable speed mud disposal pumps pump the red mud and the sands from the sands classifier in the clarification and washing unit to the red mud disposal area.

A caustic cleaning system, including all necessary storage tanks, heaters, pumps and piping, is included for the cleaning of the red mud filtration equipment.

3.1.2.4. RED MUD DISPOSAL

A red mud disposal area is provided to contain the red mud pumped from the filtration unit in the Clarification and Mud Washing area. In order to ensure compliance with environmental requirements, the disposal area has been constructed to keep seepage and egress of waste liquor remaining within the disposed mud to a minimum. The red mud will be disposed of in layers or stacks. The pipeline discharging the red mud at the disposal area is adjusted/relocated as each layer reaches a predetermined elevation.

3.1.2.5. LIME SLAKING AND STORAGE

The production of alumina from bauxite requires lime usage at the following locations: the bauxite grinding area, clarification area, filter press and organic removal (oxalate control). Depending on the availability of limestone or burned lime (i.e., pebble lime), the lime plant may encompass both or one of the following two systems.

(a) Lime burning plant complete with facilities for unloading crushed limestone, stockpiling, reclaiming, burning the limestone in oil-fired kilns, crushing the burned lime, and conveying it to a storage bin in the burned lime storage area.

(b) Lime storage and lime slaking complete with facilities for receiving and storing burned lime, weighing and conveying burned lime to slakers, slaking the lime, removing coarse solids, storing lime slurry; pumping slurry to bauxite grinding, clarification, filter press and organic removal area.

In the event limestone is used, both systems would be required. In the event burned lime is used, only the second system would be required. This estimating system assumes burned lime is used.

The lime storage and lime slaking facilities include the following: storing the burned lime; weighing and conveying the burned lime from storage bin to the slakers; slaking the burned lime with diluted caustic to produce a lime slurry; storing lime slurry for an approximate 8-hour requirement; pumping and metering lime slurry to the bauxite grinding, clarification, filter press and organic removal system for process use.

The lime storage and lime slaking facilities are open air construction. The slakers, tanks and other equipment

carrying lime slurry are subject to scaling by calcium carbonate and other deposits, thus acid cleaning facilities are provided.

3.1.2.6. ACID HANDLING AND STORAGE

The acid handling and storage unit includes tankage and controls required to receive both sulfuric (98%) and hydrochloric (35%) acids; and to prepare and distribute diluted and inhibited acids to various process units and to the powerhouse. Included are facilities for receiving and unloading road tankers. The stored acid, either sulfuric or hydrochloric, can be pumped into its associated blending tank where inhibitor can be added using variable speed metering pumps. Blending tanks are equipped with agitators. The mixed acid is pumped from the blending tanks to acid cleaning tanks in the various facilities. Sulfuric acid goes to the digestion unit, evaporation unit and the process water storage. Hydrochloric acid goes to the digestion and filter press unit. A neutralized acid tank is located in the acid storage area. The spent acid, from the process units requiring acid cleaning services, is returned to the tank for neutralization before disposal to the mud disposal system. The acid unloading and storage area is an open-air facility.

3.1.2.7. SETTLING AIDS

The settling aid facilities prepare a flocculant (starch) to be used as a settling aid in the clarification and mud washing unit to accelerate settlement of the red mud.

The facility consists of a starch unloading system with dust control equipment, starch bulk storage silos, conveying and controlled feeding systems from silos to a mixing tank, transfer pumps to starch slurry holding tanks, caustic storage tanks with agitators, prepared starch storage tank and metering pumps for distribution of starch to settlers and washers.

Starch is unloaded from bulk road carriers and discharged into the storage silos equipped with dust collectors. The dry starch is discharged from the bottom of the silos to a batch mixing tank via weigh feeders and conveyors. Water is added in the mixing tank plus a quantity of caustic soda to prevent fermentation. The starch slurry is pumped to storage tanks, each designed to hold approximately one day's supply. Starch slurry is drawn from one storage tank continuously and pumped to the prepared starch storage tank. Diluted caustic which has been prepared and stored in the diluted caustic storage tanks is pumped into the prepared starch storage tanks and mixed with the starch slurry. The proportions of starch slurry and diluted caustic are regulated to obtain a predetermined mixture which is then

steam heated and cooked. The final starch solution is distributed to the mud settlers and washers in the clarification area.

3.1.2.8. CAPITAL COSTS CALCULATION (DIRECT CONSTRUCTION COSTS)

The breakdown of costs for each unit process in the Clarification and Mud Washing, Filtration Area is as follows:

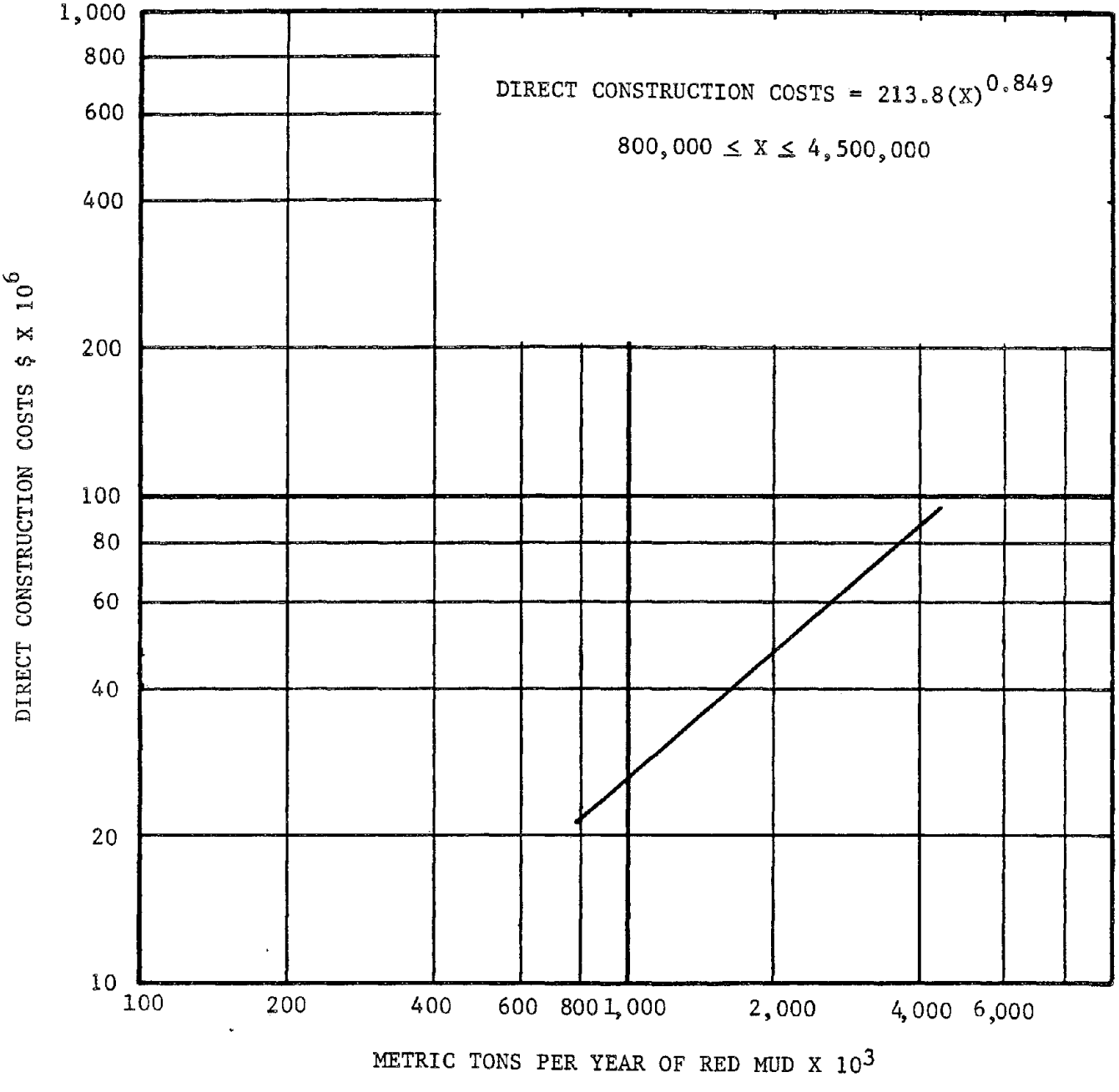
Clarification and Mud Washing	47%
Filter Press	19%
Red Mud Filtration/Disposal	17%
Lime Slaking and Storage	10%
Acid Handling and Storage	2%
Settling Aids	5%

The direct construction costs for the Clarification, Mud Washing and Filtration Areas are provided by the following cost curve for alumina plants ranging in capacity from 1,200,000 to 6,800,000 metric tons per year of bauxite consumed. The costs are subdivided into the following components:

Labor	35%
Material	31%
Equipment Usage	10%
Equipment	24%

The regression equation is:

$$\text{Direct Construction Costs} = 213.8(X)^{0.849}$$



3.1.2. CLARIFICATION AND MUD WASHING, FILTRATION

SCALE–LOGARITHMIC

3.1.3. HEAT INTERCHANGE, PRECIPITATION, HYDRATE CLARIFICATION AND EVAPORATION

3.1.3.1. HEAT INTERCHANGE

The equipment and facilities in the Heat Interchange Area performs the following major functions. This unit process cools the filtered pregnant liquor from the filter press unit by means of vacuum flash cooling. The flash steam from the cooling operation is used to preheat the spent liquor returning from precipitation on its way to the digestion unit via the evaporation plant.

Filtered pregnant liquor is pumped from the filter press unit to the heat interchange unit where it passes through a number of flash tanks in series. The liquor is successively flash cooled in each stage. The flash vapor resulting from the cooling is routed to the shell side of an associated bank of heat exchangers. From the final flash tank, the pregnant liquor flows to a barometric flash tank where it is cooled to the desired temperature before being pumped to the precipitation area. The barometric flash tank is equipped with a barometric condenser, steam ejector, seal leg and hotwell.

Spent liquor is pumped from the precipitation area through the tube side of a bank of heat exchangers, in series; the spent liquor running countercurrent to the pregnant liquor in the flash tanks. The spent liquor is heated progressively in the heat exchangers by condensing the flash vapor from the flash tanks. Each flash tank and heater stage has the capability of being bypassed for maintenance and cleaning. The hot spent liquor is then fed to the evaporation unit for further processing. Condensate from the flash tanks and from the heat exchangers is collected and transferred to the appropriate tank in the digestion area for clean or dirty condensate. Caustic cleaning of piping and equipment is required periodically.

3.1.3.2. PRECIPITATION

Precipitation or crystallization of the alumina trihydrate (hydrate) is achieved in several process trains of precipitator tanks by seeding the cooled pregnant liquor, feeding from the heat exchange unit, with hydrate seed. The precipitator tanks are arranged in series utilizing a continuous "cascade" crystallization or precipitation process. The tanks are air agitated to promote intimate mixing of the seed and pregnant liquor. Each train provides for the precipitation of the hydrate in stages with integral interstage flash cooling of the liquor. Initial separation of the hydrate from the spent liquor at the completion of the precipitation cycle is performed in hydraulic classifiers or

hydroclones with final clarification of the spent liquor being achieved in large settlers or seed thickeners. The precipitation unit is an open air facility consisting of a large "tank farm" with a common top platform.

Pregnant liquor is fed into the precipitation unit from the heat exchange unit and enters the first precipitation stage together with primary and fine seed from the hydrate classification area. The liquor is agitated within the precipitator and flows forward through the first and consecutive stages by gravity overflow. Between the consecutive stages, the hydrate slurry flows through a flash stage where the slurry is flash cooled. A hydraulic classification system receives the precipitated hydrate from the various precipitation stages. Coarse or final product discharges to surge tanks and is pumped to the calcination area. Undersized or seed hydrate is returned to the precipitation train for seeding of the incoming pregnant liquor. A caustic cleaning system is provided, including heat exchangers, pumps and piping.

3.1.3.3. HYDRATE CLASSIFICATION

The separation of hydrate from spent liquor and classification of hydrate into product size hydrate and seed hydrate is performed in hydraulic classifiers or hydrocyclones. Final clarification of the spent liquor is achieved in large diameter settlers or tertiary thickeners. The thickeners are cone bottom tanks with open tops and are equipped with rake mechanisms.

Overflow from the precipitation area flows to the settler (seed thickeners). The fine seed settles out and is raked by the rake mechanism to the underflow nozzle of the tank and pumped out to seed storage tanks. Seed is transferred from the storage tanks to the first stage of precipitators in the precipitation unit. Overflow spent liquor from the settler (seed thickener) feeds by gravity to a surge tank. The spent liquor is pumped to the evaporation unit and the heat exchange units prior to returning to the main liquor recycle stream.

3.1.3.4. EVAPORATION UNIT

The equipment and systems within the evaporation unit are required to evaporate a quantity of water from the spent liquor stream coming from the precipitation area prior to the return of the concentrated spent liquor to digestion for recycling into the process. Evaporation is required in order to maintain water balance in the plant and to increase the caustic content of the spent liquor. The evaporation system is an outdoor installation with equipment mounted in a structural steel framework.

A complete multi-stage liquor evaporator increases the caustic concentration of the spent liquor stream returning from the precipitation area via the heat interchange unit. The evaporation unit includes flash tanks, shell and tube heaters, vertical multiple effect evaporators, barometric condenser, ejectors and hotwell. Piping and valves are installed to allow bypassing any unit in the evaporator or to bypass the evaporator in its entirety. The evaporator circuit consists of a series of flash stages, each stage consisting of a flash tank, a tube and shell heat exchanger and a condensate flash tank.

Spent liquor enters a stage of regenerative heat exchangers prior to passing through an additional stage of indirect heat exchangers utilizing direct steam from the power station. The heated spent liquor then passes through the series of flash tanks where steam is given off and the spent liquor cooled. The cooled and concentrated spent liquor is pumped through an additional stage of indirect heat exchangers and then returned to the spent liquor stream-feeding the digestion unit.

Steam evolved in the lowest pressure flash tanks is condensed in surface condensers cooled by process cooling water. The live steam condensate and regenerative condensate is combined and pumped to the digestion area. An acid cleaning system is provided complete with storage tanks, pumps and piping. Connections are provided to allow for periodic caustic cleaning of the vessels and heat exchangers.

3.1.3.5. CAPITAL COSTS CALCULATION (DIRECT CONSTRUCTION COSTS)

The costs of each unit process in the Heat Interchange, Precipitation, Hydrate Classification and Evaporation Area are shown as follows as a percentage of the total area cost.

Heat Interchange	4%
Precipitation and Hydrate Classification	78%
Evaporation	18%

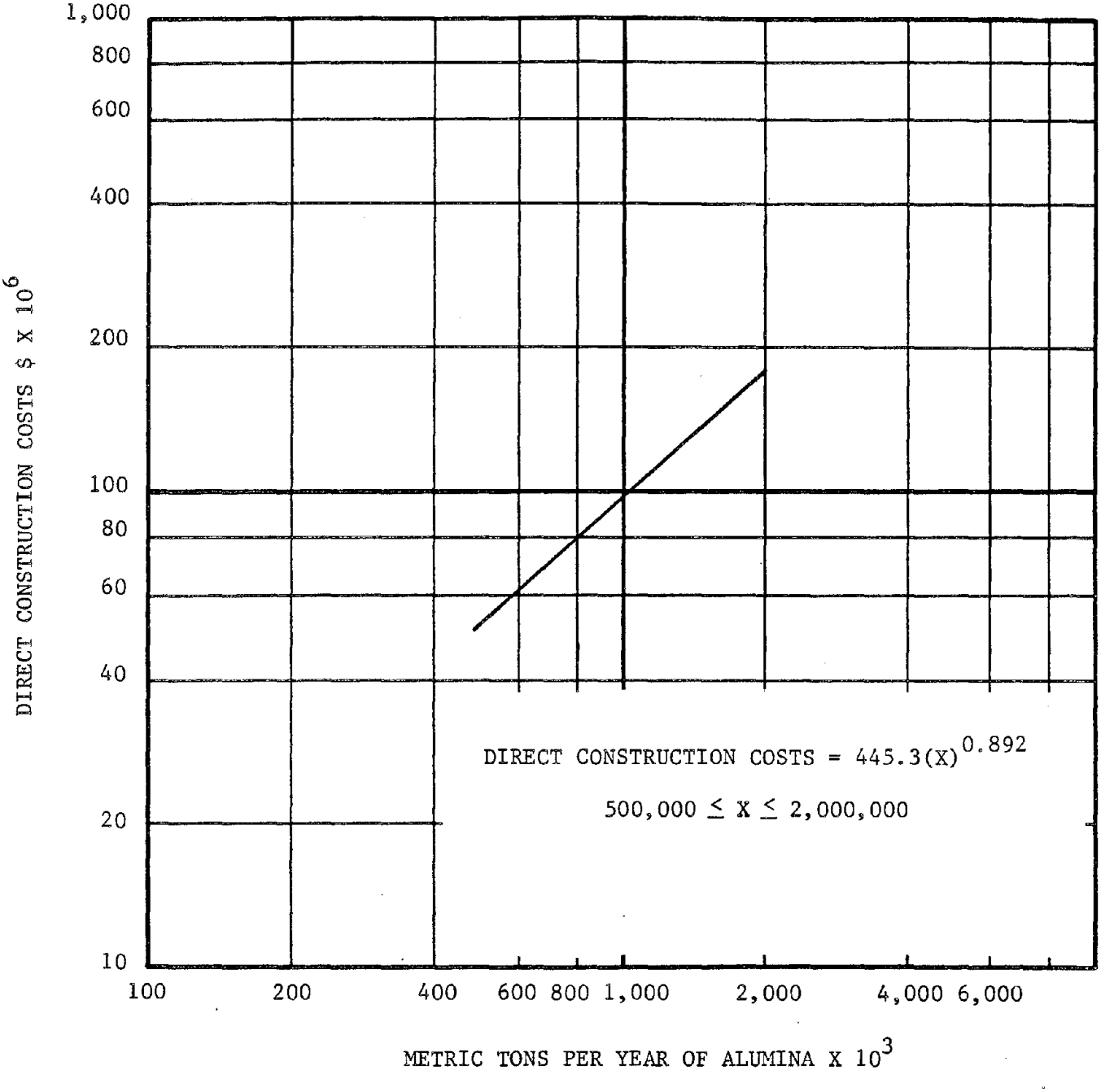
The costs for evaporation will decrease should high temperature digestion be selected with the cost adjusted downward via a .67 multiplier.

The direct construction costs for the Heat Interchange, Precipitation, Hydrate, Classification and Evaporation Area are provided by the following cost curve for alumina plants ranging in capacity from 500,000 to 2,000,000 metric tons per year. The costs are subdivided into the following components:

Labor	32%
Material	25%
Equipment Usage	11%
Equipment	32%

The regression equation is:

$$\text{Direct Construction Costs} = 445.3(X)^{0.892}$$



3.1.3. HEAT INTERCHANGE, PRECIPITATION, HYDRATE CLASSIFICATION AND EVAPORATION

SCALE--LOGARITHMIC

3.1.4. CALCINATION AND ALUMINA STORAGE

3.1.4.1. HYDRATE FILTRATION AND CALCINATION

Calcination is the final process step in the production of alumina. The calcination unit consists of two parts. The first filtration, includes hydrate storage tanks and hydrate filters with all necessary ancillary equipment. The second part of this facility covers the calcination of hydrate to alumina and includes fluidized bed calciners and support equipment, such as electrostatic precipitator, cyclones, conveying systems, burners and alumina coolers.

Hydrate Filtration Included in the Hydrate Filtration Area are the following facilities:

- Hydrate storage tanks to store the alumina trihydrate slurry produced in the precipitation unit
- Density control tanks to control density of the hydrate slurry prior to filtration
- Hydrate pan filters to deliquor, wash and dewater the hydrate prior to feeding it to the fluid bed calciners.

The filtration section of the calcination unit is in an enclosed multi-story building structure. An elevator common to both the filtration section and to the calciner section is provided.

The hydrate slurry received from the precipitation unit is stored in the hydrate storage tanks. Underflow from the hydrate storage tanks flows by gravity to the hydrate density control tanks where the hydrate is diluted so as to maintain a controlled flow rate to the hydrate filters. The hydrate filters deliquor and wash the hydrate and reduces its soda content to specified levels. The soda level is achieved by using a countercurrent wash system. The deliquored and washed cake is discharged from the filter to the calciners. Caustic cleaning equipment is provided for cleaning of major wet process equipment.

Circulating Fluids Bed Calciners The process functions of the calcining system are as follows:

- Hydrate drying and preheating
- Calcining
- Cooling
- Flue gas cleaning.

Three distinct operations are required in the calciners in order to convert the alumina trihydrate to the specification grade alumina. In the first operation, hot flue gases from the calciner dries the hydrate being fed and reduces the amount of chemically bound moisture. The dried hydrate is transferred to the calcining section where the final calcining temperature will be achieved by combustion of the fuel. In the third stage, heat from the calcined alumina is used to preheat the combustion air. Cooling of the alumina will be accomplished in a fluid bed cooler. The outgoing alumina is transported to the alumina storage unit via an air activated gravity conveyor system with air type lifts. Flue gas cleaning equipment is provided to meet the applicable air pollution regulations. The collected dust is returned to the calcining system.

3.1.4.2. ALUMINA STORAGE AND RECLAIM

The function of this facility is to receive the alumina product from the calcination facility and convey it to the top of alumina storage silos for distribution to the selected silo. The silo reclaim system has the capability of reclaiming, conveying and feeding the reclaimed alumina into railway cars through a rail load-out system. The load-out system is equipped with railway track scales which automatically weigh and record the quantity of alumina being outloaded.

Alumina Transfer Into Storage Alumina is discharged from the fluid bed calciners into an air activated gravity conveyor system feeding to an airlift system which elevates the alumina for distribution into the storage silos. The alumina discharging from the airlift system is fed into a "spider" distribution system which evenly delivers the alumina into the selected storage silo. The spider distribution system is arranged to minimize segregation of the alumina in the silo.

The silos and alumina transfer system are equipped with dust collectors and fans. Alumina is reclaimed from the storage silos utilizing an internal reclaim system consisting of open type air activated gravity conveyors. These conveyors fluidize the stored alumina, when required, so as to maintain a reclaim rate to allow for rapid filling of the railway cars. The air activated gravity conveyors feed to an arrangement of telescopic load-out spouts complete with dust control take-off points. After completion of loading, each car is automatically weighed and the weight recorded.

3.1.4.3. CAPITAL COSTS CALCULATION (DIRECT CONSTRUCTION COSTS)

Individual unit process costs are shown as a percentage of the total area costs as follows:

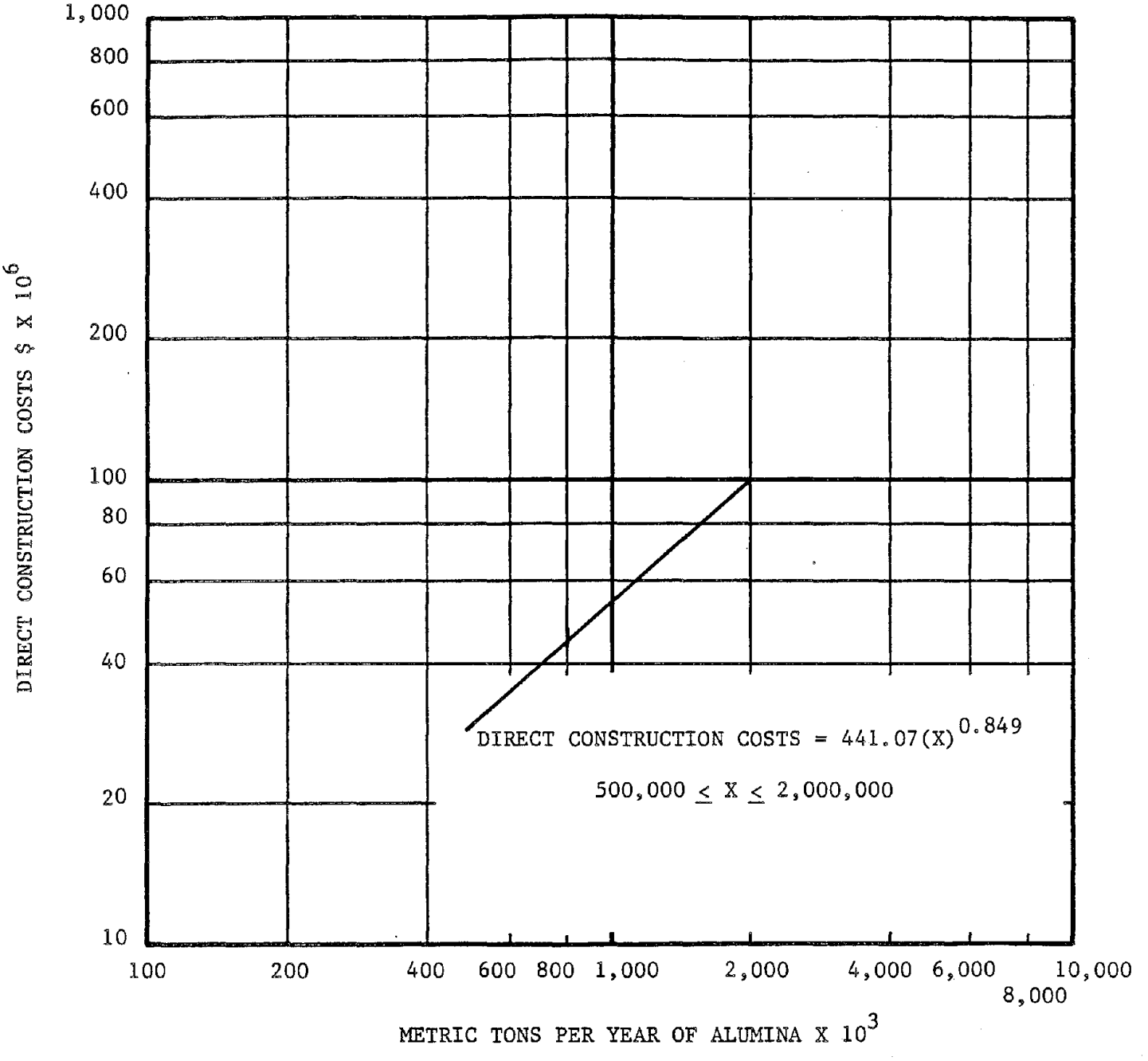
Hydrate Filtration and Calcination	66%
Alumina Storage and Reclaim	34%

The direct construction costs for the Calcination and Alumina Storage Area are provided by the following cost curve for alumina plants ranging in capacity from 500,000 to 2,000,000 metric tons per year. The costs are subdivided into the following components:

Labor	25%
Material	11%
Equipment Usage	5%
Equipment	59%

The regression equation is:

$$\text{Direct Construction Costs} = 441.07(X)^{0.849}$$



3.1.4. CALCINATION AND ALUMINA STORAGE

SCALE—LOGARITHMIC

3.1.5. ALTERNATIVE UNIT PROCESSES

3.1.5.1. LIME PLANT

The lime burning facilities furnish a continuous supply of burned lime to the lime storage and lime slaking area. The plant consists of a system for unloading crushed limestone, conveying the limestone to stockpiles, reclaiming the limestone and conveying to a kiln, burning the limestone in an oil-fired kiln, cooling burned lime, crushing the lime, conveying the lime to the burned lime bin.

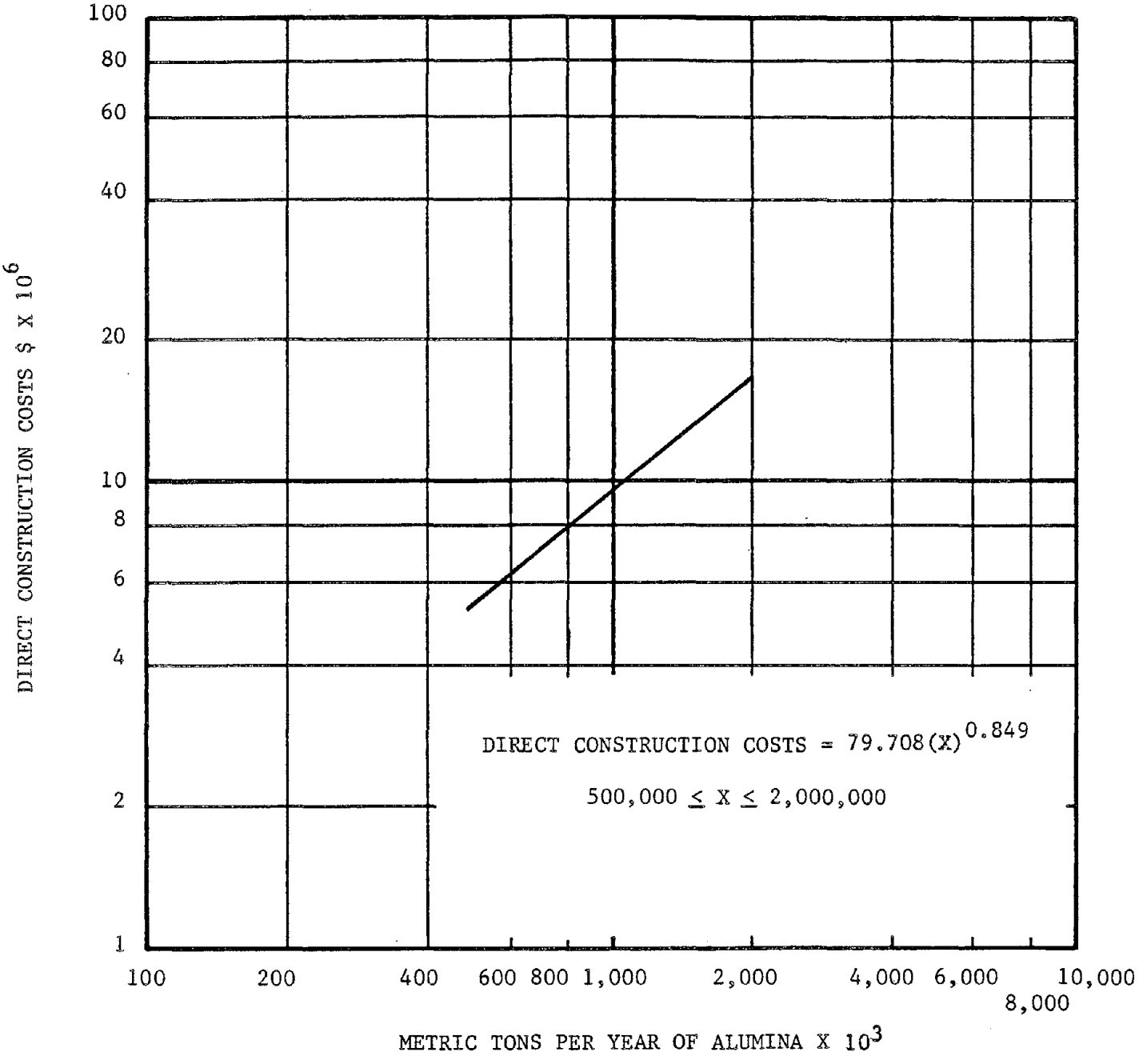
The lime burning plant has all environmental control equipment, limestone bin, cooler conveyors, receiving hopper and ancillary equipment.

The direct construction costs for the Lime Plant Area are subdivided into the following categories:

Labor	25%
Materials	11%
Equipment Usage	5%
Equipment	59%

The regression equation is:

$$\text{Direct Construction Costs} = 79.708(X)^{0.849}$$



3.1.5.1. LIME PLANT

SCALE—LOGARITHMIC

3.1.5.2. ORGANIC REMOVAL

Sodium oxalate derived from organic matter associated with the bauxite feed adversely affects hydrate precipitation. The oxalate removal system included is designed to remove the oxalates and other impurities from the plant liquor stream, such that the concentrations of these contaminants are maintained at an acceptable level. The organic removal system is installed within a structural multi-story building which is roofed and sheeted.

A portion of the underflow stream from the seed thickeners is pumped to a filter building where the seed is washed on a rotary filter. The solid phase oxalate on the seed is dissolved and the resulting oxalate rich filtrate is fed to an oxalate destruction unit. The filtrate from which the oxalate is removed is returned to the main process spent liquor stream. Connections for caustic cleaning of the equipment are included.

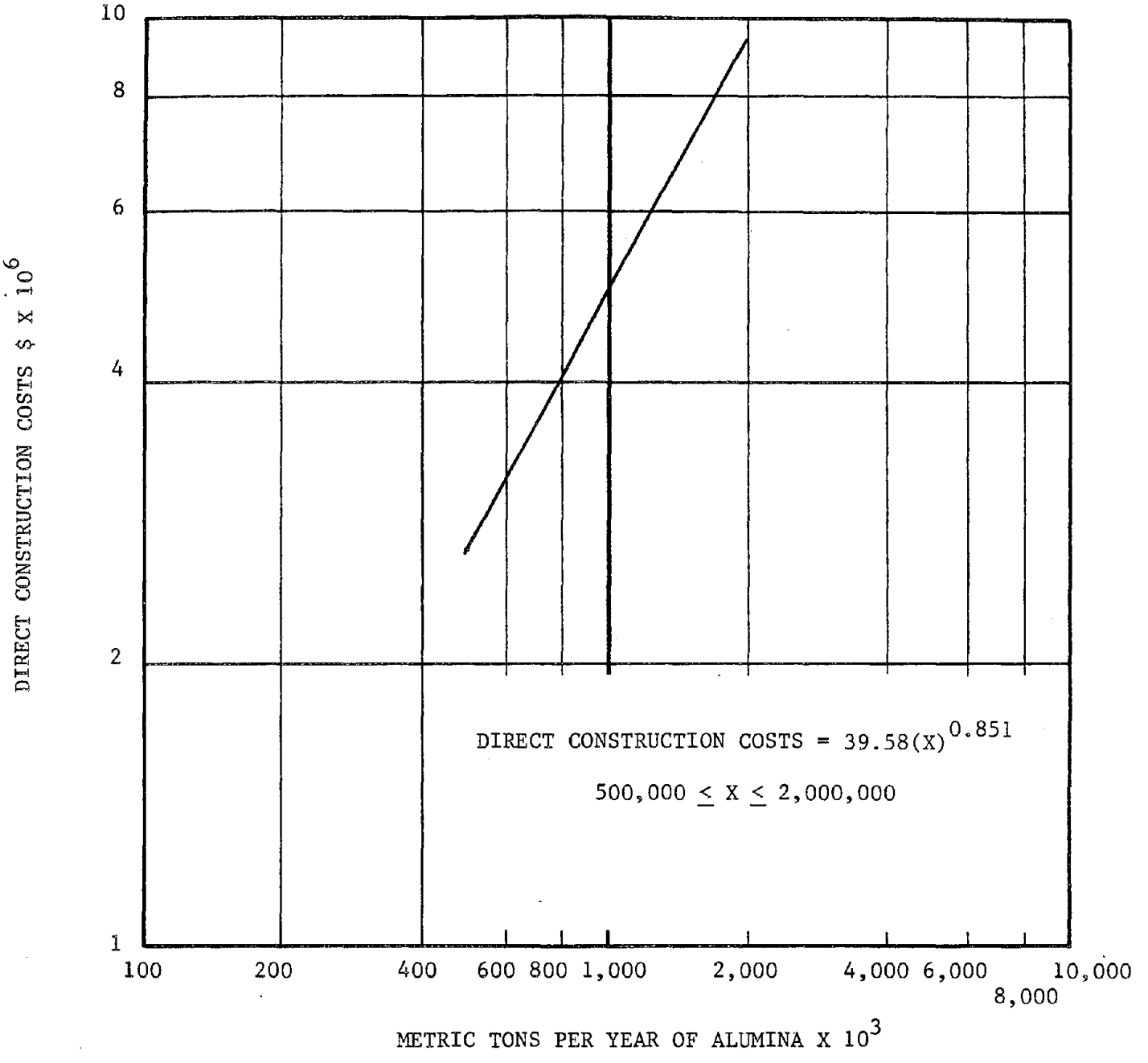
3.1.5.3. CAPITAL COSTS CALCULATION (DIRECT CONSTRUCTION COSTS)

The direct construction costs for the Organic Removal Area are provided by the following cost curve for alumina plants ranging in capacity from 500,000 to 2,000,000 metric tons per year. The costs are subdivided into the following components:

Labor	34%
Material	25%
Equipment Usage	11%
Equipment	30%

The regression equation is:

$$\text{Direct Construction Costs} = 39.58(X)^{0.851}$$



3.1.5.2. ORGANIC REMOVAL

SCALE—LOGARITHMIC

3.2. GENERAL FACILITY COSTS

3.2.1. GENERAL PLANT

3.2.1.1. SITE

Site preparation includes the clearing, grubbing and preparation of the land at the refinery site; leveling of individual building sites and process areas; the preparation and paving of all roads within the refinery and designated roads leading to remote facilities of the refinery, parking lots and all laydown areas; and the preparation of all railway beds within the refinery limit.

Included under General Facility Costs (process) are yard pipe racks and the piping (outside pipelines) which transfer the various liquors from one process unit to another. Piping within the battery limits of each process unit is considered an integral part of that particular unit. All piping between the battery limits of the process units, carried on the pipe racks, is considered as yard piping. The following is a listing of the major pipe systems routed along the pipe racks: steam, water, compressed air, caustic, bauxite slurry, green liquor, spent liquor, hose water, hose liquor, starch slurry, lime slurry, acid and fuel oils.

The storm drainage system is designed to handle a storm with a 50 year return cycle, based on assumed local rainfall figures.

Within the refinery limits, storm sewer lines are open channels. Outside the immediate limits of the refinery drainage is by means of open ditches or pipe.

3.2.1.2. COMPRESSED AIR

Four air compressor are located in the power plant. Taking ambient air, the compressors filter, compress, cool, and in the case of instrument air, dry the air. Air receivers store the compressed air to protect the air system against surges in demand.

3.2.1.3. FUEL OIL STORAGE AND DISTRIBUTION

Fuel oil unloading facilities include - for the unloading of road tankers - stations to unload up to four tankers simultaneously.

The fuel oil storage tanks are per A.P.I. standard and are protected by bunds and a foamite system.

The fuel storage tanks are equipped with steam suction heaters. A pumping station and piping system for circulating

oil to the calcination unit and also to the power facility is included.

3.2.1.4. DIESEL FUEL STORAGE AND DISTRIBUTION

Diesel fuel unloading facilities include capacity for the unloading of two diesel road tankers simultaneously. The unloading is accomplished by one of two pumps. The piping arrangement is such that the pumps can be used for either the unloading or distribution of the diesel oil to various facilities. A storage tank is included and is a standard A.P.I. storage tank protected by bunding and a foamite system. Diesel fuel is distributed to the calcination unit, powerhouse, and garage and heavy vehicle equipment shed.

3.2.1.5. SANITATION SYSTEM

The sanitary sewer system serves all offices, restrooms, and control rooms with toilets, shower or kitchen facilities. It is sized and designed to handle all raw sanitary sewage in accordance with applicable health regulations and codes for sewage treatment plant design and operation. The effluent from the sewage plant is fed to the refinery process water lake or reservoir. The digested sludge is disposed of into the red mud disposal.

3.2.1.6. PRIMARY WATER PLANT AND STORAGE

The unit consists of a system with the capability of treating, storing and supplying the refinery with potable water. Untreated water is fed in from a refinery fresh water lake and treated as necessary to produce an acceptable potable water. In general, the treatment consists of flocculation, clarification, filtration and chlorination. The treated water is stored in water storage tanks for treated/fire water distribution.

Treated water is delivered to a storage surge tank from where water is pumped to the process water distribution system.

A refinery process and cooling water reservoir is included in the plant process water facilities. It has been assumed that such a reservoir would receive total rain runoff from the refinery site, including rain collected on all open slabbed areas during heavy rainfall periods. The sumps normally handling process spillage on the slabs would be set to discharge to the refinery process water reservoir so as to keep dilution of the process liquor to a minimum. Cooling water for both the refinery and power plant are taken from and returned to the reservoir. Process cooling water pump stations are located in the process and power plant areas.

A fresh-water lake has been constructed in the locality of the refinery so as to ensure an adequate and continuous supply of fresh water to the plant. The lake area, plus an additional width around the lake perimeter high water mark, is cleared of all vegetation, tree stumps, etc. The lake and dam are constructed of appropriate impervious materials. The wetted faces of the dam are constructed of rip-rap stone.

Included is a pumping station and a pipeline feeding to the refinery to both the water treatment plant and to the process water lake or reservoir.

3.2.1.7. CAPITAL COSTS CALCULATION (DIRECT CONSTRUCTION COSTS)

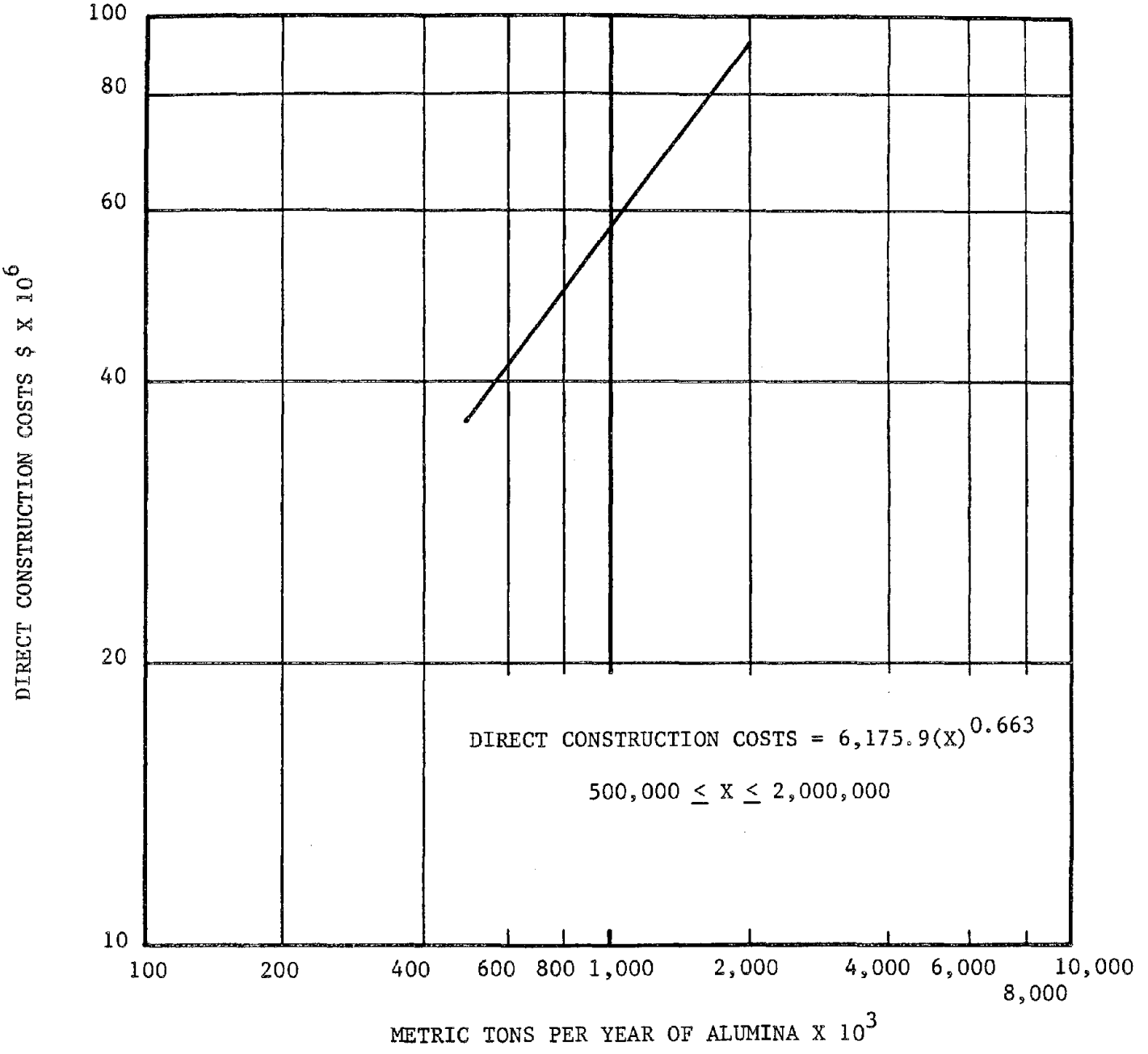
The direct construction costs for the General Plant Area are provided by the following cost curve for alumina plants ranging in capacity from 500,000 to 2,000,000 metric tons per year. The costs are subdivided into the following components:

Labor	48%
Material	29%
Equipment Usage	18%
Equipment	5%

The regression equation is :

$$\text{Direct Construction Costs} = 6{,}175.9(X)^{0.663}$$

Should the primary water and sewage treatment be provided by a utility, remove 3% of the capital costs calculated.



3.2. GENERAL FACILITY

SCALE–LOGARITHMIC

3.2.2. POWER SUPPLY SYSTEM

3.2.2.1. POWER PLANT

The power plant provides a firm supply of electricity, steam and compressed air to the refinery. Individual items of equipment are sized and spared to ensure full-load utility demands are met, even when major pieces of equipment are out of service.

The power plant is equipped with independent, identical units, each unit consisting of a coal and oil-fired boiler and an extracting, condensing steam-turbine generator located in a multi-story building. Emergency power is provided by diesel-driven generators or gas turbines. Also, four air compressors provide a supply of compressed air for instrument air, general plant service air and agitation air for the precipitation unit.

The boilers are capable of maintaining a continuous rated flow when burning coal or No. 6 fuel oil or various combinations of the two. Oil is used when coal is not available. No. 2 oil is used for ignition of the burner and is shut off after a main burner is ignited.

The boilers have numerous sub-systems and components to ensure reliability and efficiency. They include he following:

- Pulverized fuel system
- Draft system
- Air heaters
- Super-heater and super-heater attemperator
- Economizer
- Soot blowers
- Electrostatic precipitators
- Bottom ash system
- Fly ash system
- Blowdown systems.

The bottom ash system provides for final disposal of the ash by trucks to a disposal area. The fly ash is slurried and pumped to the red mud filter building and disposed of with the red mud feeding to the red mud disposal area. The turbine generators produce the power plant electricity. High-

pressure, high-temperature steam from the boilers drive the turbines, which are directly coupled to generators. Steam extracted from the turbines supplies steam to the HP feed water heaters to the power plant deaerating heaters, and to the alumina plant process steam headers.

The major turbine sub-systems are:

- o Turbine control and protective devices
- o Turbine lubricating oil system
- o Steam stop, inlet control and extraction control valves.

Emergency power is supplied to the power plant and alumina plant by diesel generators. Emergency power is required when all steam turbine generators are down at the same time. A separate emergency power system connects the diesel generators to equipment requiring emergency power. In the power plant, this is any equipment that needs power for a safe shutdown or that is required to restart the power plant. In the alumina plant, emergency power is supplied to equipment or processes that could be damaged without power. The emergency power system is capable of starting from a standstill in a complete electrical blackout. The steam turbine generators and boilers are started one at a time once the emergency diesel generators are operating.

All major power plant operations are conducted from the power plant central control room, including starting, loading, and shutdown operation of boilers, turbine generator units, air compressors, emergency diesel generators and other items of plant equipment.

3.2.2.2. ELECTRICAL DISTRIBUTION SYSTEM

With the power plant at its center, the electrical distribution system is designed and arranged to provide a reliable supply of power to the alumina process plant.

The power plant location within the refinery area is such that distances to the major electrical loads are as short as possible. The distribution system is basically radial primary with double-ended substations of a single tie breaker, secondary selective type. Feeder and transformer capacity is designed to allow for load increases and for feeder or transformer failure.

3.2.2.3. YARD LIGHTING

Yard lighting embraces all lighting for those areas generally outside the process unit area battery limits.

The yard lighting installed includes appropriate lighting for all roads; all designated parking areas; all open operating areas, such as railway loading and unloading stations, bauxite storage and reclaim area, coal storage, oil, caustic and acid storage areas; and the periphery of all operating areas.

3.2.2.4. COMMUNICATION SYSTEM

Telephone System. The telephone system consists of a 425-line system with a processor controlled digital switching technique. The refinery is serviced by fixed, mobile and portable radio systems which comprise a number of VHF and UHF repeaters. Working via these repeaters are numerous fixed control stations, mobile installations installed in various plant vehicles and a large number of portable radios. The UHF frequencies are intended for in-plant use. The VHF frequencies are for red mud disposal and general security use over longer distance.

The refinery is equipped with a public address system consisting of internally and externally mounted speakers. The system is broken down into areas with each area having its own amplifier and being accessed from its associated control room. The system is tied into the telephone system so as to give access to each area individually or to all areas simultaneously.

3.2.2.5. CAPITAL COSTS CALCULATION (DIRECT CONSTRUCTION COSTS)

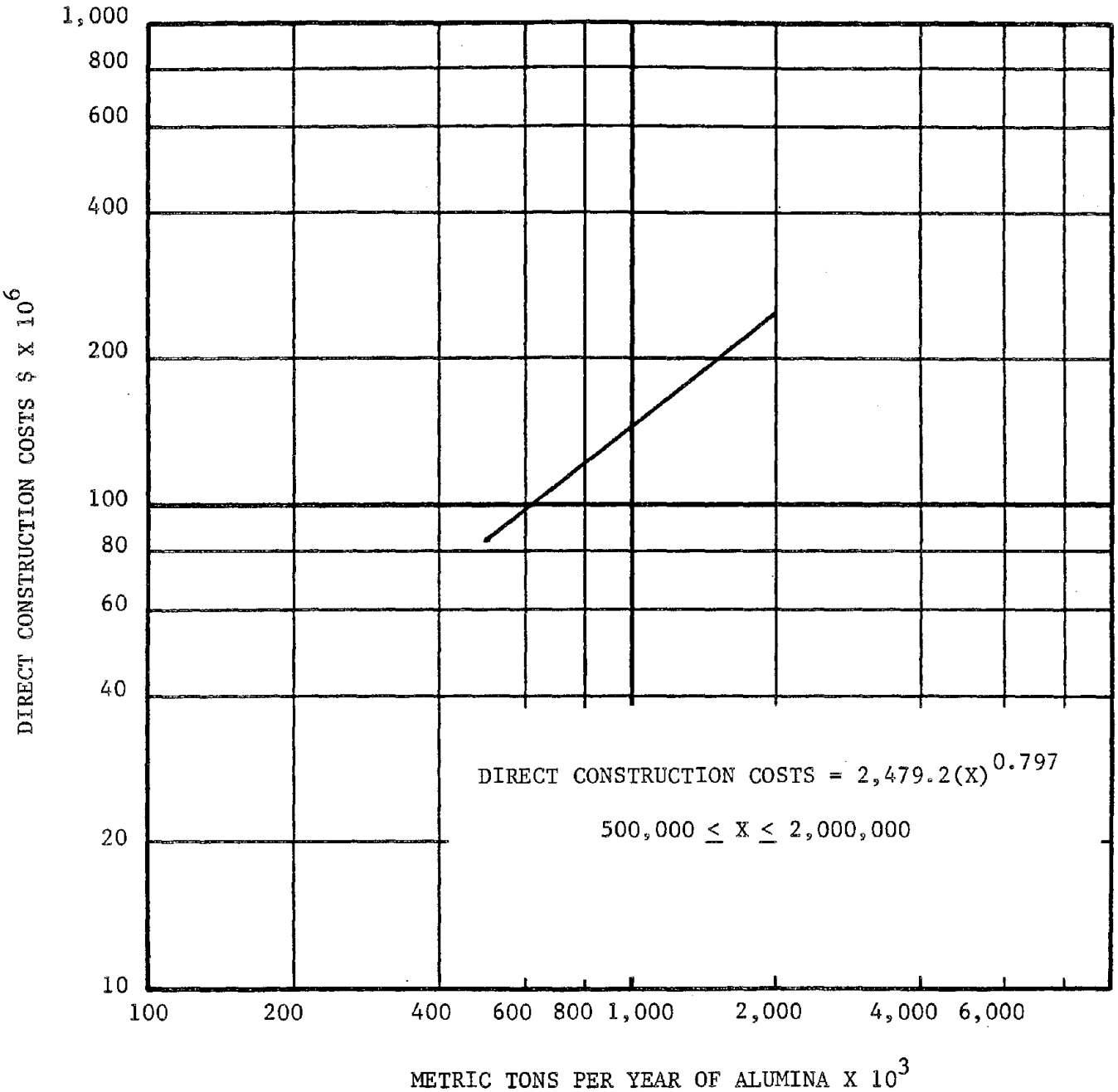
The direct construction costs for the Power Supply System are provided by the following cost curve for alumina plants ranging in capacity from 500,000 to 2,000,000 metric tons per year. The costs are subdivided into the following components:

Labor	24%
Material	9%
Equipment Usage	5%
Equipment	62%

The regression equation is:

$$\text{Direct Construction Costs} = 2{,}479.2(X)^{0.797}$$

Should power be purchased instead of generated on site, no turbine generators would be required. The power house costs amount to 68% of the total Power Supply System Costs. The turbine generators account for 33% of the power house costs; thus, the total cost must be reduced by this amount.



3.2.2. POWER SUPPLY SYSTEM

SCALE—LOGARITHMIC

3.2.3. MATERIALS HANDLING

3.2.3.1. WHARF

The wharf facility includes the equipment to off-load bauxite, coal and to load product alumina for distribution to market. The facility includes a skip loader and unloader with transport of materials to the adjacent refinery.

3.2.3.2. COAL HANDLING

The coal unloading and storage area receives and stores coal for the power plant. Coal is transported in bottom dump rail cars which pass over a bridge and dump the coal into a large basin from which bulldozers move the coal to a storage area. Coal is reclaimed through an underground tunnel equipped with reclaim equipment. The coal is transported by a single conveyor belt to a transfer station, then passes through a crushing and sampling system prior to delivery by tripper conveyor to the power plant.

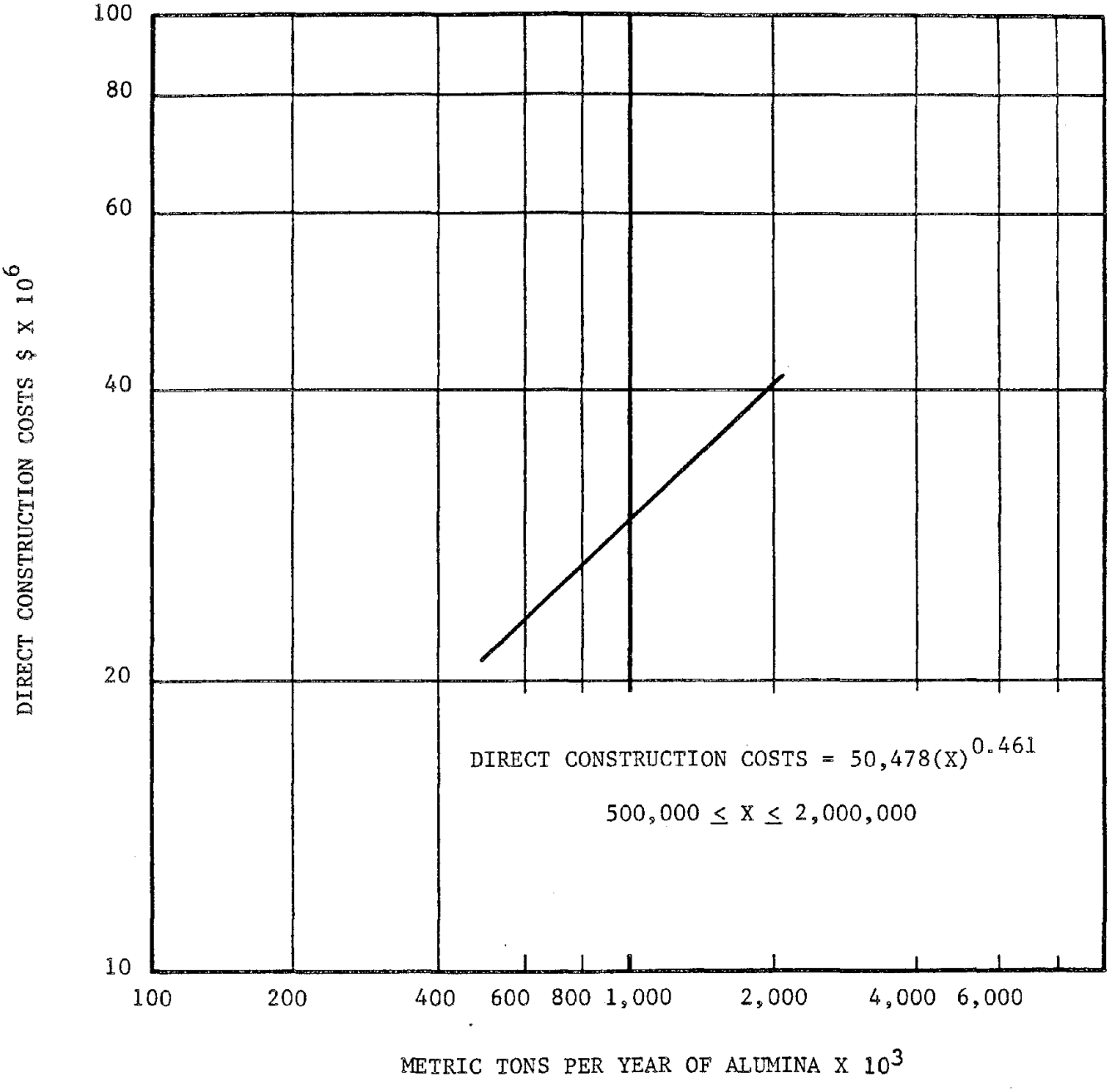
3.2.3.3. CAPITAL COSTS CALCULATION (DIRECT CONSTRUCTION COSTS)

The direct construction costs for the Material Handling Area are provided by the following cost curve for alumina plants ranging in capacity from 500,000 2,000,000 metric tons per year. The costs are subdivided into the following components:

Labor	28%
Material	30%
Equipment Usage	11%
Equipment	31%

The regression equation is:

$$\text{Direct Construction Costs} = 50{,}478(X)^{0.461}$$



3.2.3. MATERIALS HANDLING

SCALE—LOGARITHMIC

3.2.4. ADMINISTRATION BUILDING/SERVICES

3.2.4.1 ADMINISTRATION BUILDING AND LABORATORY

The administration building is a one-story pre-engineered building with a steel frame, reinforced concrete floor, insulated metal siding with brick veneer, drywall partitions, tile floors and carpeted offices.

The building houses staff personnel consisting of: general manager, operations manager, technical manager, comptroller, industrial relations, engineering, purchasing, traffic, accounting and data processing. An entrance way with lobby and conference rooms make up the remaining floor area.

The laboratory section houses the office of the chief chemist and staff and laboratories as follows: sample preparation room, spectrograph room, atomic absorption laboratory, automated laboratory, wet laboratory, balance room, film storage, record storage, reagent storage, mechanical equipment room plus lockers and shower area.

3.2.4.2. PERSONNEL SERVICES BUILDINGS

The facilities may be separate buildings or under one roof. The basis for this costing system includes:

- Change House which contains showers, wash basins and personnel lockers
- Training Center which houses a training area office and storeroom
- Security and Medical Building which houses security offices, laboratory and offices for a doctor and nurse, medical facilities and a fire and ambulance station
- A Gatehouse for plant entry control is located adjacent to the security and medical building.

3.2.4.3. AREA CONTROL ROOMS AND MAINTENANCE OFFICES

Area Control Rooms are provided for the operation of the refinery. Each of the control rooms is equipped with a microprocessor-based Distributed Control System (DCS) with Visual Display units for operator-process interface. Within each area, Programmable Logic Controllers (PLC's) are used for digital logic sequencing and interlocking of pumps, drive motors, etc., with necessary input-outputs to the Distributed Control System for motor control or status display.

Each area control room contains:

- o Visual display units for process control and monitoring
- o Video screen copier
- o Alarm printers and computer printers

The Distributed Control System in each area control room is connected to a main process computer in the administration building for collection of data, process graphic generation and process report generation.

The area maintenance offices are equipped with vent fans, lockers, tables, rack shelving, tool lockers and pedestal grinders and are serviced by a monorail with hoist.

3.2.4.4. CAPITAL COSTS CALCULATION (DIRECT CONSTRUCTION COSTS)

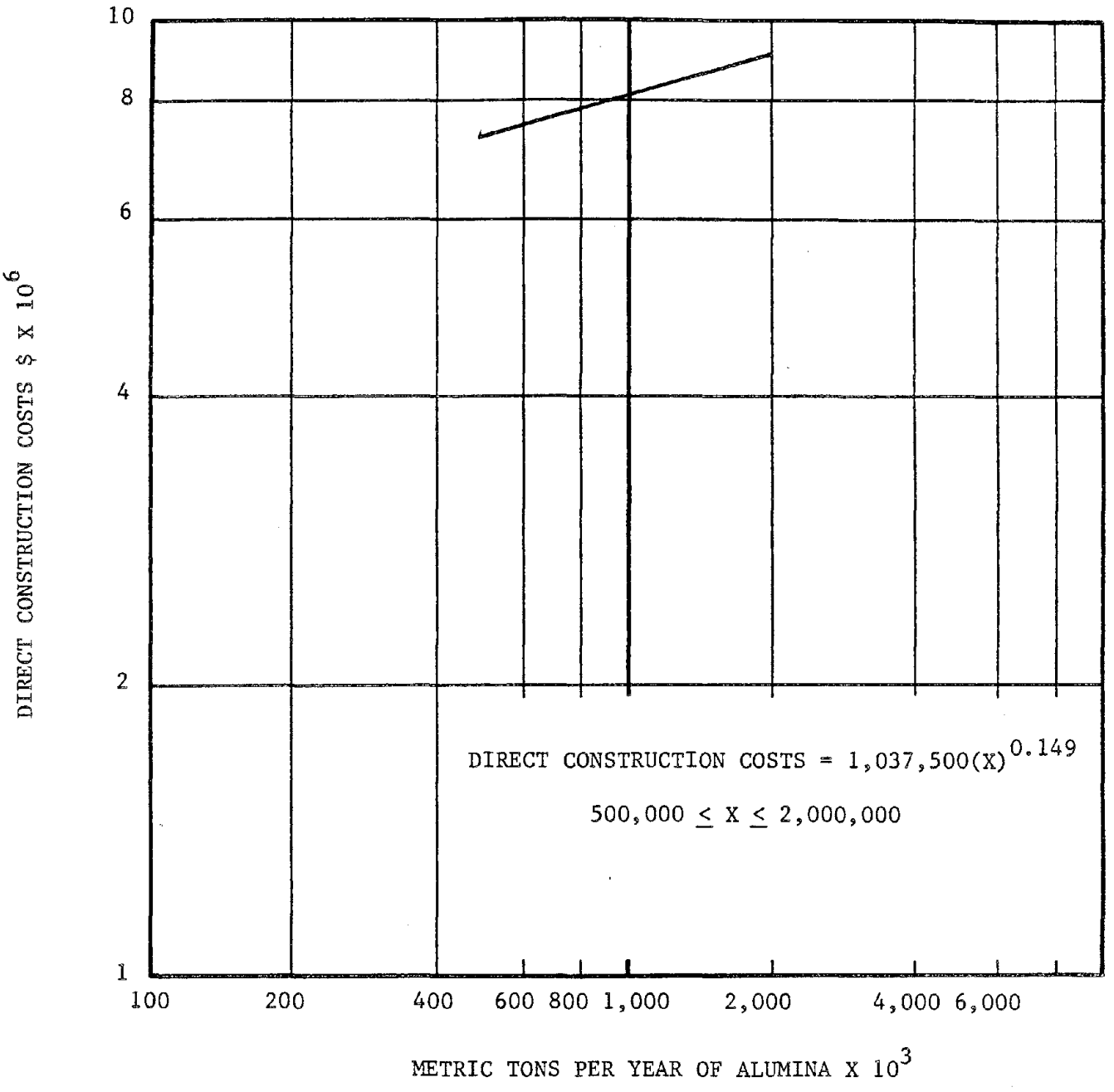
The direct construction costs for the Area Control Rooms and Maintenance Office are provided by the following cost curve for alumina plants ranging in capacity from 500,000 to 2,000,000 metric tons per year. The costs are subdivided into the following components:

Labor	48%
Material	29%
Equipment Usage	4%
Equipment	19%

The regression equation is:

$$\text{Direct Construction Costs} = 1{,}037{,}600(X)^{0.149}$$

This page is intentionally blank



3.2.4. ADMINISTRATION BUILDINGS

SCALE–LOGARITHMIC

3.2.5. SERVICES BUILDINGS

3.2.5.1. MAINTENANCE FACILITIES

The Maintenance Shop buildings are one-story pre-engineered structures with a structural steel frame, reinforced concrete floors, insulated metal roofing and siding, concrete block interior walls, drywall construction for interior offices and tile floors. Offices include those for the maintenance superintendent and general offices for craft supervisors. Shops include: fabrication shop, machine shop, welding shop, carpentry shop, electrical shop, pipe fabrication shop, instrument repair shop, garage, heavy equipment shed and equipment cleaning building.

Travelling bridge cranes are installed in the buildings and jib cranes are located at individual machines or work areas.

Major machine tools are included within the machine shop, such as lathes, vertical boring mills, milling machines, grinders, vertical hydraulic presses, band saws, etc.

The welding shop is supplied with a heat-treating furnace and welding equipment.

3.2.5.2. WAREHOUSES

The warehouses are one-story pre-engineered structures with a structural steel frame, reinforced concrete floors, insulated metal roofing and siding, lock interior walls and painted floors.

Offices include those for clerical and administrative personnel assigned to the receiving and shipping of materials. The warehouse has a dock for loading and unloading materials. Shelving in the main storage area are included to organize the location of spare parts.

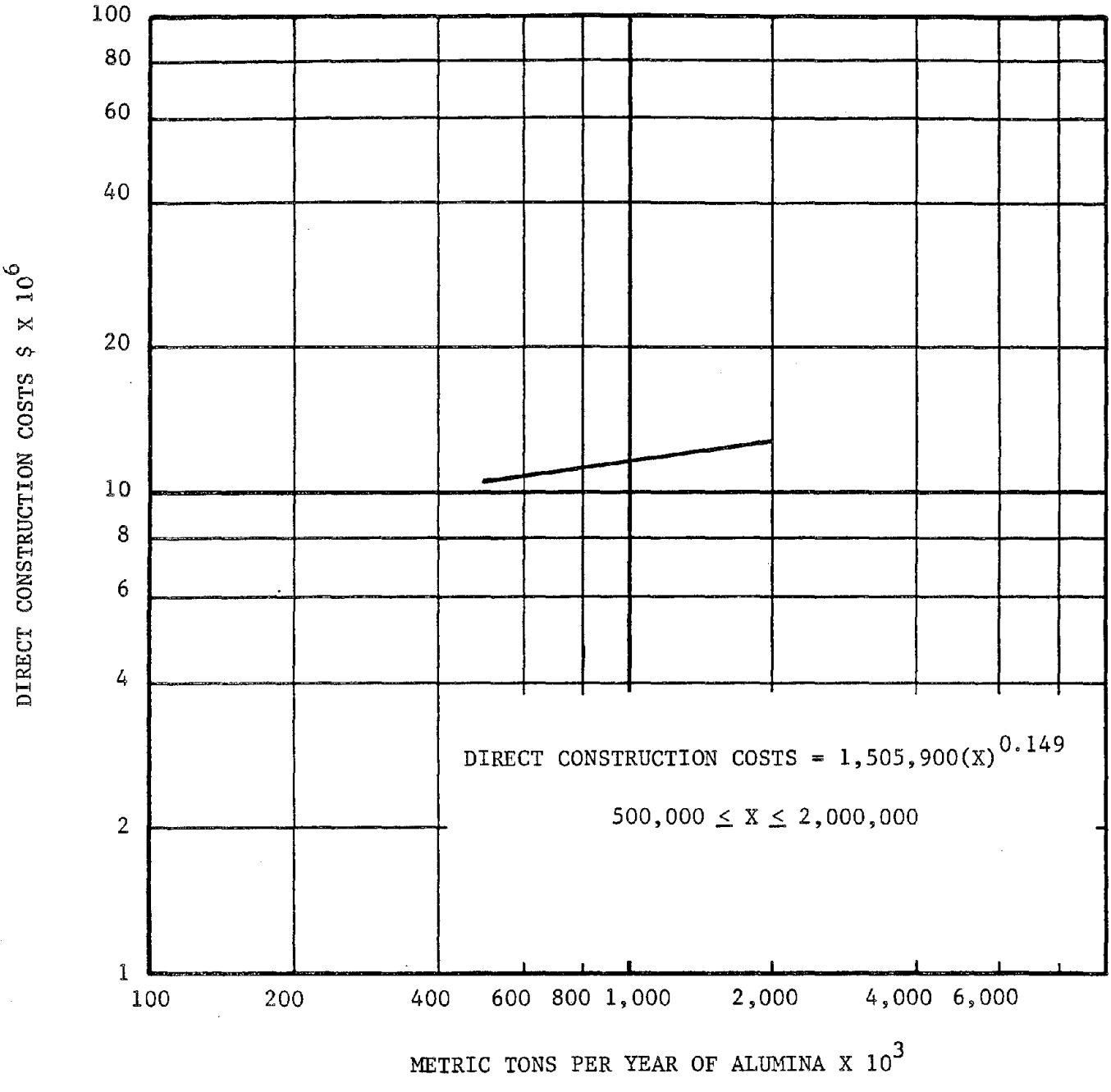
3.2.5.3. CAPITAL COSTS CALCULATION (DIRECT CONSTRUCTION COSTS)

The direct construction costs for the Maintenance Shop and Warehouses are provided by the following cost curve for alumina plants ranging in capacity from 500,000 to 2,000,000 metric tons per year. The costs are subdivided into the following components:

Labor	42%
Material	32%
Equipment Usage	5%
Equipment	21%

The regression equation is:

$$\text{Direct Construction Costs} = 1{,}805{,}900(X)^{0.149}$$



3.2.5. SERVICES BUILDINGS

SCALE—LOGARITHMIC

3.3. ENVIRONMENTAL CONTROL SYSTEMS DIRECT COSTS

Bauxite and alumina handling and transfer facilities are ventilated to minimize dust emission. The exhaust from the bauxite and alumina handling equipment as well as calcination is adequately treated to control the particulate level to 50 mg/m^3 (.022 gr/dscf) in the discharged gases as required by the federal regulations.

The limestone handling and lime kiln facilities, if included, are also provided with adequate pollution control systems to control the particulate emission to 0.3 lb/ton of lime in the exhaust gases as required by the federal regulations.

3.3.1. REFINERY CONTROL SYSTEMS

3.3.1.1. BAUXITE SLURRY PREPARATION

Bauxite Storage and Reclaim. The storage and reclaim facility is designed for the storage of bauxite and the reclaiming of bauxite to be fed to the bauxite grinding and slurrying facility.

To control particulate emission, dust collectors are installed at reclaim conveyors transfer points. The dust collectors are filter-bag type with reversible air-jet type cleaning. The cleaned air is discharged to atmosphere and the collected dust is returned to the conveyor belt.

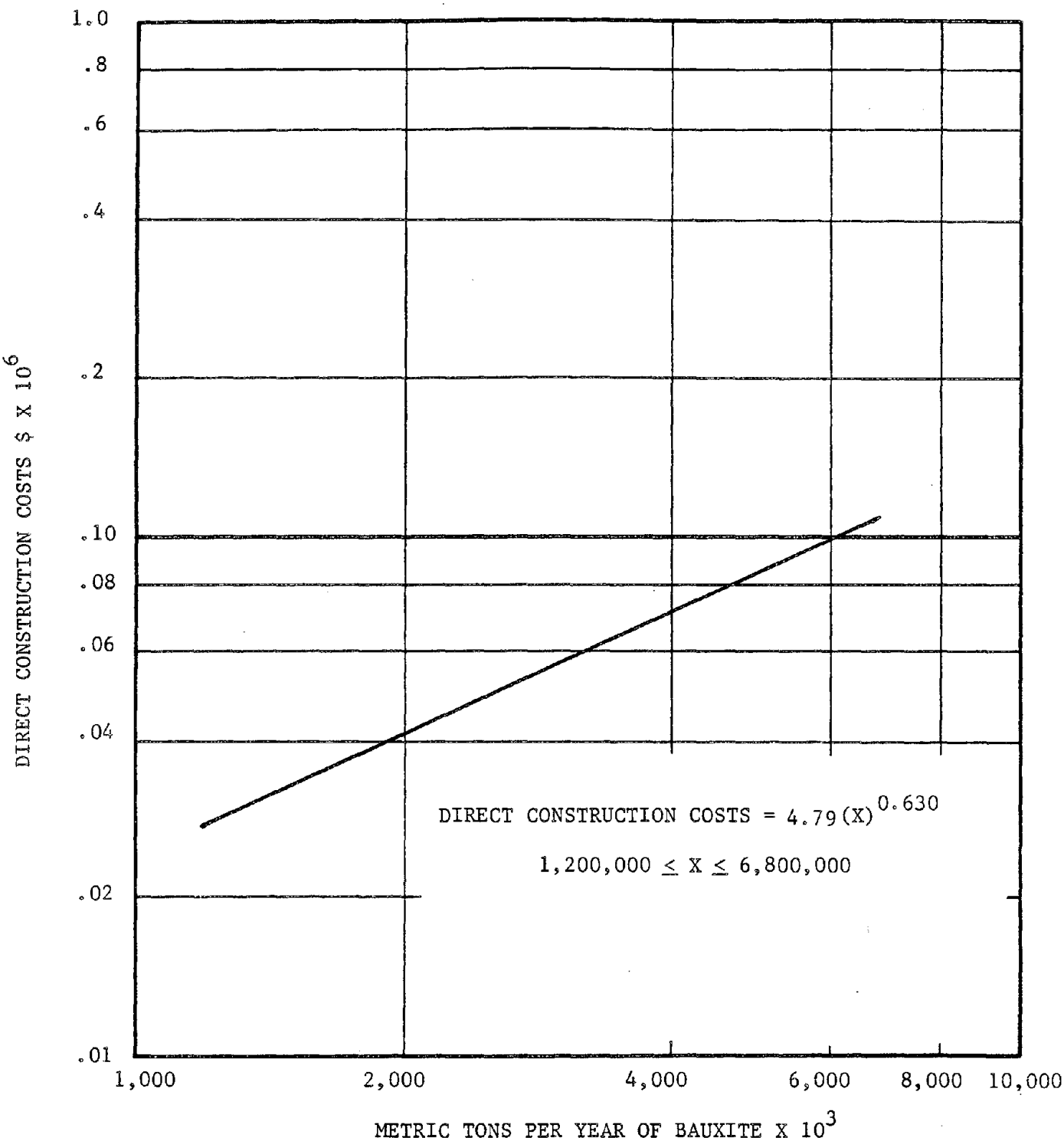
Bauxite Grinding and Slurrying. Dust collectors are installed at the top of the bauxite storage bins and at the point of transfer from the trippers conveyors. Dust collectors are similar to those previously described. Bin-mounted dust collectors are installed in each of the bauxite storage bins. Each of the three conveyors feeding from the bauxite storage bins to the grinding mills is equipped with dust collectors.

The direct construction costs can be obtained from the cost curve following. The costs are subdivided as follows:

Labor	26%
Material	14%
Equipment Usage	3%
Equipment	57%

The regression equation is:

$$\text{Direct Construction Costs} = 4.79(X)^{0.630}$$



3.3.1.1. BAUXITE SLURRY PREPARATION

SCALE—LOGARITHMIC

3.3.1.2. CLARIFICATION AND MUD WASHING

Bauxite refining uses process water for boiler feed water, washing precipitates and for dilution of pregnant (green) liquor. These water uses produce the major wastestream, "Red Mud", containing the impurities rejected from the bauxite. Secondary wastestreams include air scrubber effluents, barometric condenser effluents, contact cooling water, chemical cleaning wastes, boiler blowdown and spills and leaks. A further wastestream consists of salts removed from the evaporator.

The two solid wastestreams, Red Mud and salts, are conveyed off-site for disposal in an approved landfill. Clarified overflow water is recycled. All other wastestreams are available for direct recycle within the unit processes as washwater makeup.

Condensate from the evaporation step is added to the mud washer to recover caustic soda. The bottom flow from the mud washer, the Red Mud", is conveyed to an approved landfill. Because the "Red Mud" contains the impurities rejected from the bauxite ore, this landfill must conform to standard engineering practice to protect surface and ground water contamination from the suspended solids, inorganic compounds and elevated pH characteristics of the "Red Mud".

The landfill is constructed of earthen materials including the liner which will be clay-bearing native material. If clay-bearing material is unavailable, native material will be admixed with bentonite clay or soil cement to produce a percolation rate of 10^{-5} cm/sec. Sufficient capacity for holding the mud for at least six months shall be planned, including 3-ft freeboard before discharge of clarified decant. Also included in this design will be sufficient capacity for the annual rainfall minus the combined evaporation and percolation rates. In wetter climates where complete containment may not be feasible, the landfill will be designed, constructed and operated to prevent nuisance conditions such as mosquitoes.

Prior to locating the landfill, tests shall be conducted on the location of groundwater, soil bearing capacity and percolation rates; the location of the landfill will be based on availability of land providing suitable characteristics for these parameters.

Hygienic wet air scrubber, barometric condensers, machinery contact cooling, boiler blowdown and miscellaneous spills and leaks are collected and reused in the mud washer.

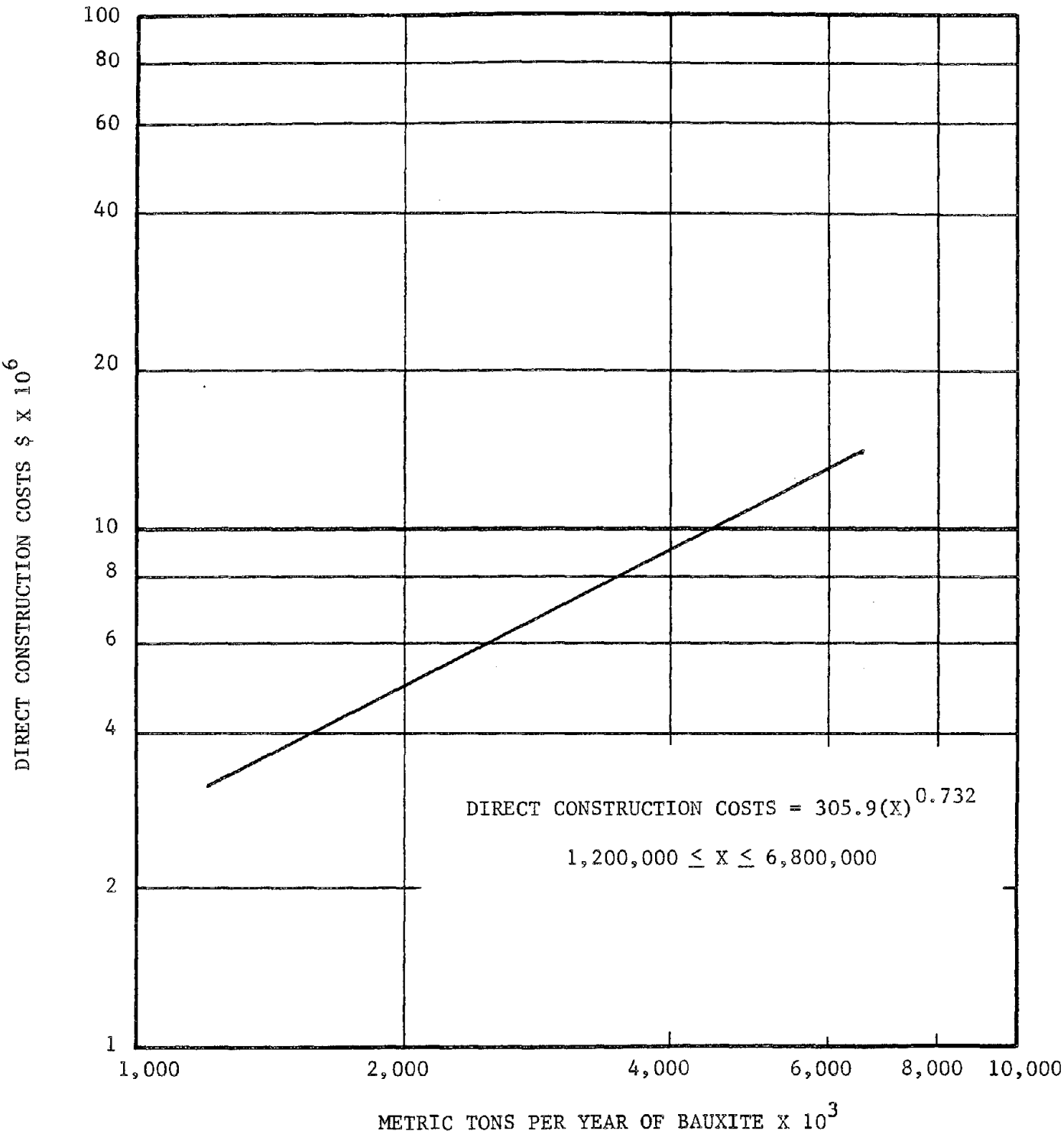
The direct construction costs for the wastewater/red mud disposal system can be obtained from the cost curve. The

costs are divided as follows:

Labor	32%
Materials	45%
Equipment Usage	7%
Equipment	16%

The regression equation is:

$$\text{Direct Construction Costs} = 305.9(X)^{0.732}$$



3.3.1.2. CLARIFICATION AND MUD WASHING

SCALE—LOGARITHMIC

3.3.1.3. CALCINATION AND ALUMINA STORAGE

Calcination. The alumina hydrate slurry is filtered and calcined in a fluid bed calciner system. An electrostatic precipitator system is installed downstream of the calciner to recover the alumina and to reduce the emission level to 50 mg/m^3 (.022 gr/dscf) in the exhaust gases. The alumina dust is recovered from the calciner gases and the cleaned gas is discharged into the atmosphere through a stack.

The dust recovery system is considered an essential process operation and is not therefore costed separately in this section.

Alumina Handling and Storage. Alumina is transferred from the calciners to the storage silos by means of air activated gravity conveyors. Venting of the air activated gravity conveyors is performed by dust collectors. (Filter-bag type with reverse jet-air cleaning.) Silos are adequately vented to dust collectors installed in each silo.

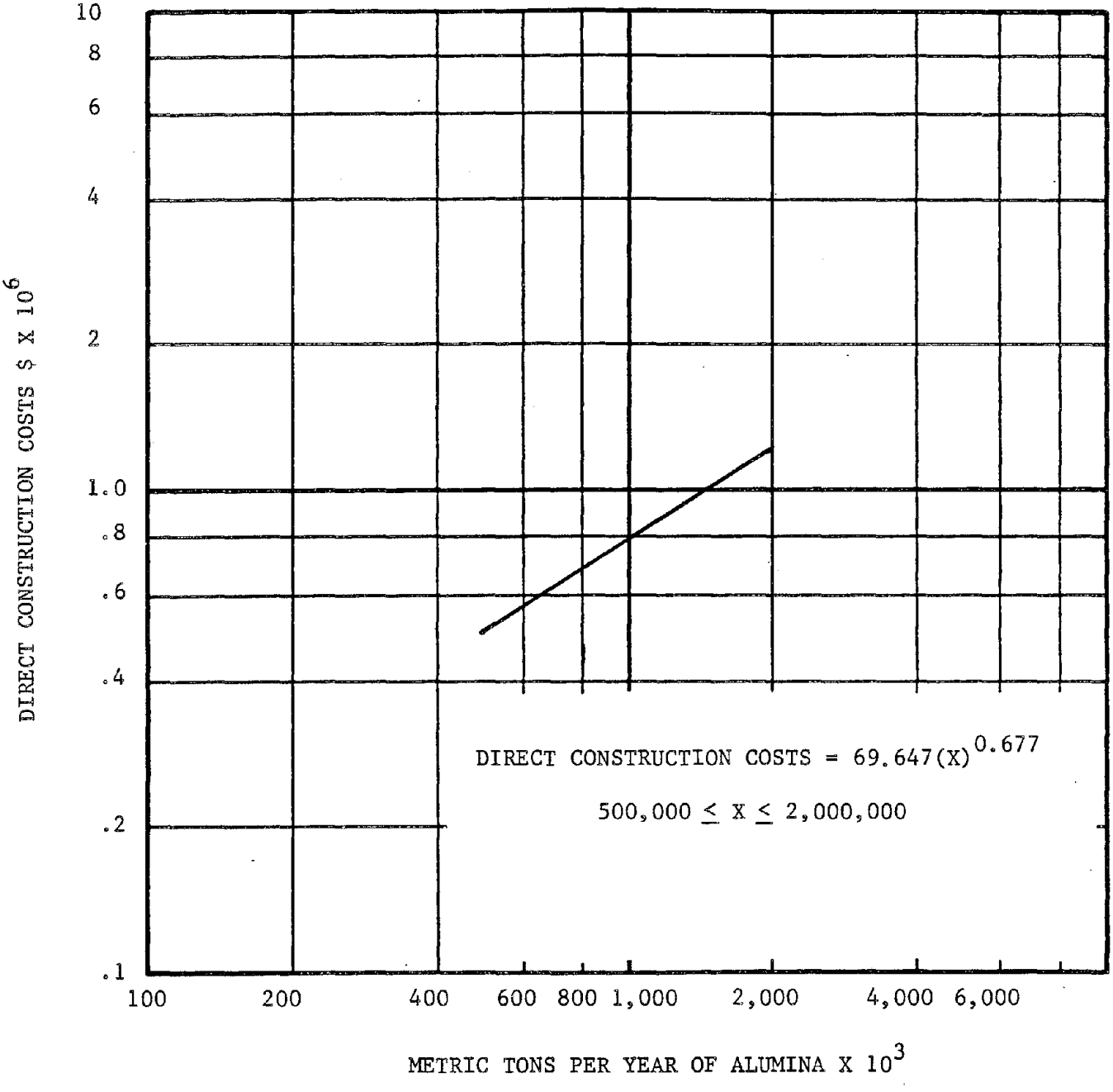
The reclaim system from the silos is also fitted with dust collectors.

The direct construction costs are provided by the following curve. The costs are subdivided into the following components:

Labor	26%
Material	14%
Equipment Usage	3%
Equipment	57%

The regression equation for the costs is:

$$\text{Direct Construction Costs} = 69.647(X)^{0.677}$$



3.3.1.3. CALCINATION AND ALUMINA STORAGE

SCALE—LOGARITHMIC

3.3.1.4. STARCH AND LIME PLANT AREAS

A dilute starch solution is prepared and added to each operating settler and washer as a settling aid.

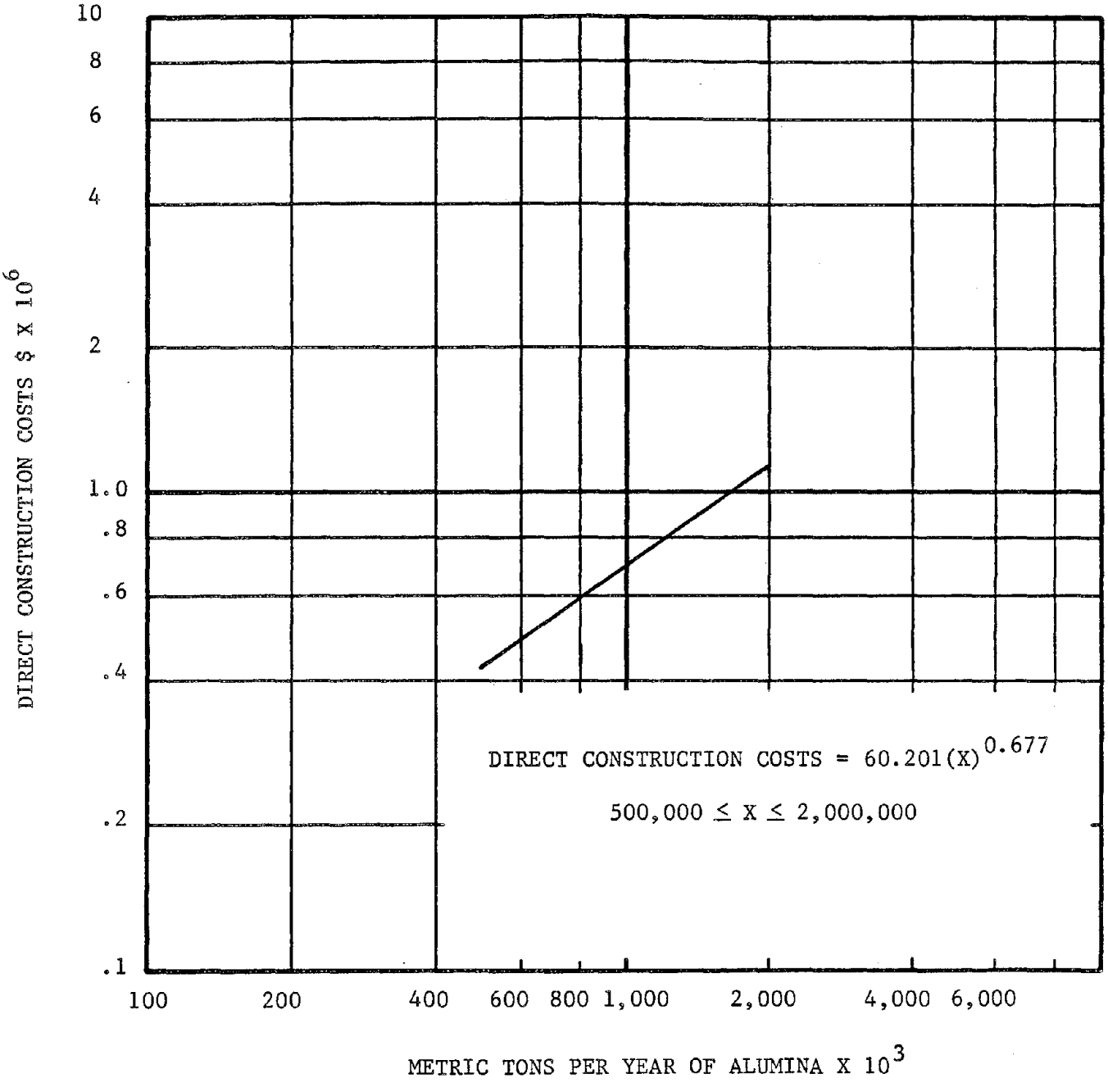
The starch is transported to a storage bin by a pneumatic conveying system. A fabric filter type dust collector is provided over the starch storage bin to filter the discharged air. Similar facilities are provided for the lime handling system.

The direct construction costs for the dust collection system is provided by the curve following. The costs are subdivided into the following categories:

Labor	26%
Material	14%
Equipment Usage	3%
Equipment	57%

The regression equation is:

$$\text{Direct Construction Costs} = 60.201(X)^{0.677}$$



3.3.1.4. STARCH AND LIME PLANT AREAS

SCALE–LOGARITHMIC

3.3.2. GENERAL FACILITY CONTROL SYSTEMS

3.3.2.1. POWER PLANT

The steam generator in alumina facilities is a major source of air pollution. The United States regulations currently limit the emission of the major pollutants from the boiler exhaust as follows:

	Coal-Fired	Oil-Fired
Particulates	0.1 lb/0^6 Btu	0.1 lb/10^6 Btu
Sulfur Dioxide	1.2 lb/10^6 Btu	0.8 lb/10^6 Btu
Nitrous Oxide	0.7 lb/10^6 Btu	0.3 lb/10^6 Btu
Opacity	20%	20%

Alumina Plant Cogeneration Facility

The cogeneration facility for a mid size alumina plant would require 930 x 10^6 Btu/hr for power and steam production.

The facility would be coal-fired or oil-fired and subject to the above Federal New Source Performance Standards.

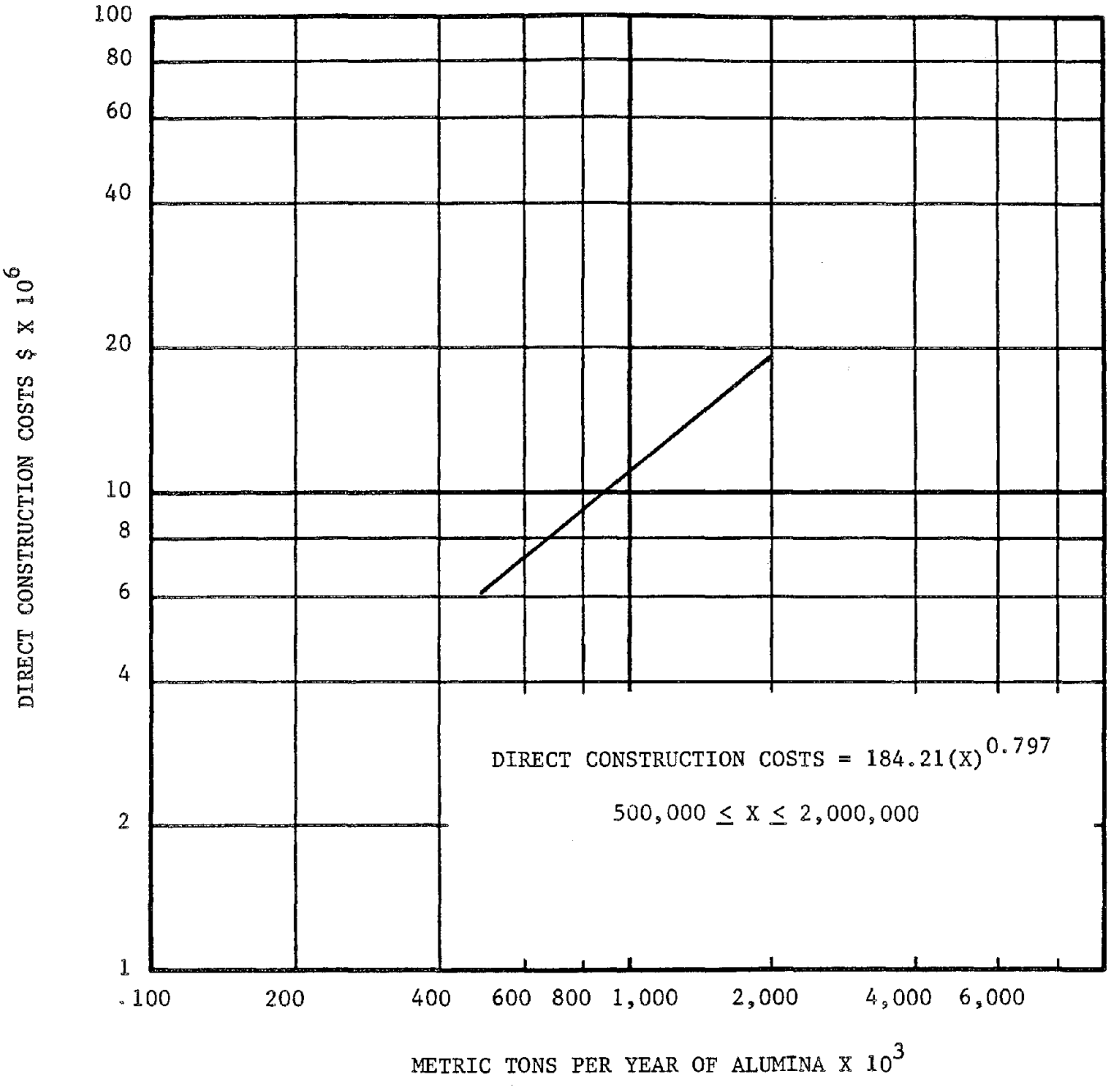
A special technique such as staged combustion is required to meet the nitrous oxide emission limitation. The particulates are controlled by an electrostatic precipitator to meet the above federal emission requirements. For high sulfur coal, a scrubber would be required.

The direct construction costs for the environmental control systems are provided by the following cost curve. The cost components are subdivided into:

Labor	38%
Material	19%
Equipment Usage	6%
Equipment	37%

The regression equation is:

$$\text{Direct Construction Costs} = 184.21(X)^{0.797}$$



3.3.2.1. POWER PLANT

SCALE–LOGARITHMIC

3.3.2.2. NOISE CONTROL

The noise standards established by Article 105 of General Industry Safety Orders by Federal OSHA (Occupational Safety and Health Administration) are applicable to all industrial plants including alumina refineries.

The OSHA regulation permits eight hours per day exposure to noise level of 90 dBA. The exposure time limit is halved for each 5 dBA increase up to the maximum permitted continuous noise level of 115 dBA.

Community noise codes are generally based on annoyance and sleep interference. The various industrial and city standards in the United States allows the continuous noise in the residential area to be between 60-65 dBA during daytime and night time due to industrial operations.

The above plant noise level is applicable to all the unit process areas of alumina refineries. In order to control the equipment noise level in the plant area, the following engineering features will be incorporated in the plant design:

- Plenums to provide low velocity air to noise sources
- Lagging for piping, vessels and valves to absorb radiated noise
- Silencers or mutes to attenuate noise from high velocity flows of gases
- Insulations for fan and other equipment to reduce noise level
- Vibration isolator mats, pads or sheets between machines and foundations or floors
- Enclosure surrounding high noise equipment such as compressors
- Flexible shaft couplings and fabric sections in ducts wherever possible.

If the above engineering controls fail to reduce sound levels within the levels specified above, personnel protective equipment such as muff-type ear protectors and ear inserts would be provided and used to reduce the noise exposure.

If the plant is located within a few hundred feed of residential community, certain measures would be required to control the noise from the plant operation. These measures

would include isolated enclosures for compressors, heavy duty neoprene pads for cooling towers, fan isolations and enclosed building with acoustical walls for process equipment.

Allowable community noise level largely depends on the community location such as rural and urban areas. If the plant location is within a few hundred feet of the residential area, a sound barrier wall surrounding the plant may be required to attenuate the noise level.

3.3.3. ENVIRONMENTAL CONTROL SYSTEMS COST ADJUSTMENT

The environmental control standards vary worldwide as illustrated by Table 3 in Section 2.5. This Section of the Alumina Handbook thus far has been devoted to identifying environmental control systems and equipment that are required for a refinery facility located in the United States to meet federal regulations. According to the variation in worldwide standards, some systems and equipment may not be required or an alternate system or item of equipment may be selected. The cost estimating system prepared for this handbook includes an adjustment capability for environmental system construction costs depending on the specific site location selected. A review of Section 2.5 will assist in the selection plus certain systems may be omitted or factored for cost adjustment.

Table 6 provides alternative technology to meet the standards that apply to the four groups of countries described in Section 2.5 and detailed in Table 3. The different categories of the gas cleaning equipment shown are required to meet the regulatory requirements of the other metal producing countries of the world.

The capital cost of various equipment sizes for a baghouse, electrostatic precipitator, scrubber or cyclone system is illustrated by means of cost factor curves as per Table 7. Different gas flows are plotted to obtain cost factor curves. The purpose of the curves is to estimate the cost of an alternative gas cleaning system from the known equipment cost of a base gas cleaning system such as provided previously in this section.

The curves provide a baseline with a cost factor of unity for a pulse jet baghouse system required in the U.S.A. to meet the most stringent air emission limit. The less stringent emission limit of the other countries can be achieved by the use of a scrubber or cyclone system.

The cost factors can be applied to the corresponding unit process cost curves prepared for this section to make the appropriate adjustment in cost for the equipment selected.

A typical example is:

A pulse jet type baghouse handling 170,000 m^3/h in the material handling area of the United States plant would cost $380,000. The baghouse would meet the particulate emission limit of 50 mg/dsm^3 as promulgated by the United States Environmental Protection Agency.

The cost factor for the venturi scrubber system at 170,000 m^3/h is read as 0.28 from the curves. Therefore, the cost of a venturi scrubber for the raw material handling area would be 0.28 x $380,000 = $107,000.

The emission limit for particulates in the Group IV countries such as Egypt and India is 300 mg/SM^3 as shown in Table 3. A multi-clone system could achieve this emission limit as shown in Table 6. The cost factor for the multi-clone at 170,000 m^3/h is read as 0.1 from the curves provided in Table 7.

Therefore, the cost of a multi-clone system for the control of particulate emissions from the concentrate handling area would be 0.1 x $380,000 = $38,000.

Capital costs for pulse jet and reverse air type baghouse, electrostatic precipitator, scrubber and cyclone were obtained for the different selected gas flow rates from a paper entitled "Capital & Operating Costs of Selected Air Pollution Control Systems".

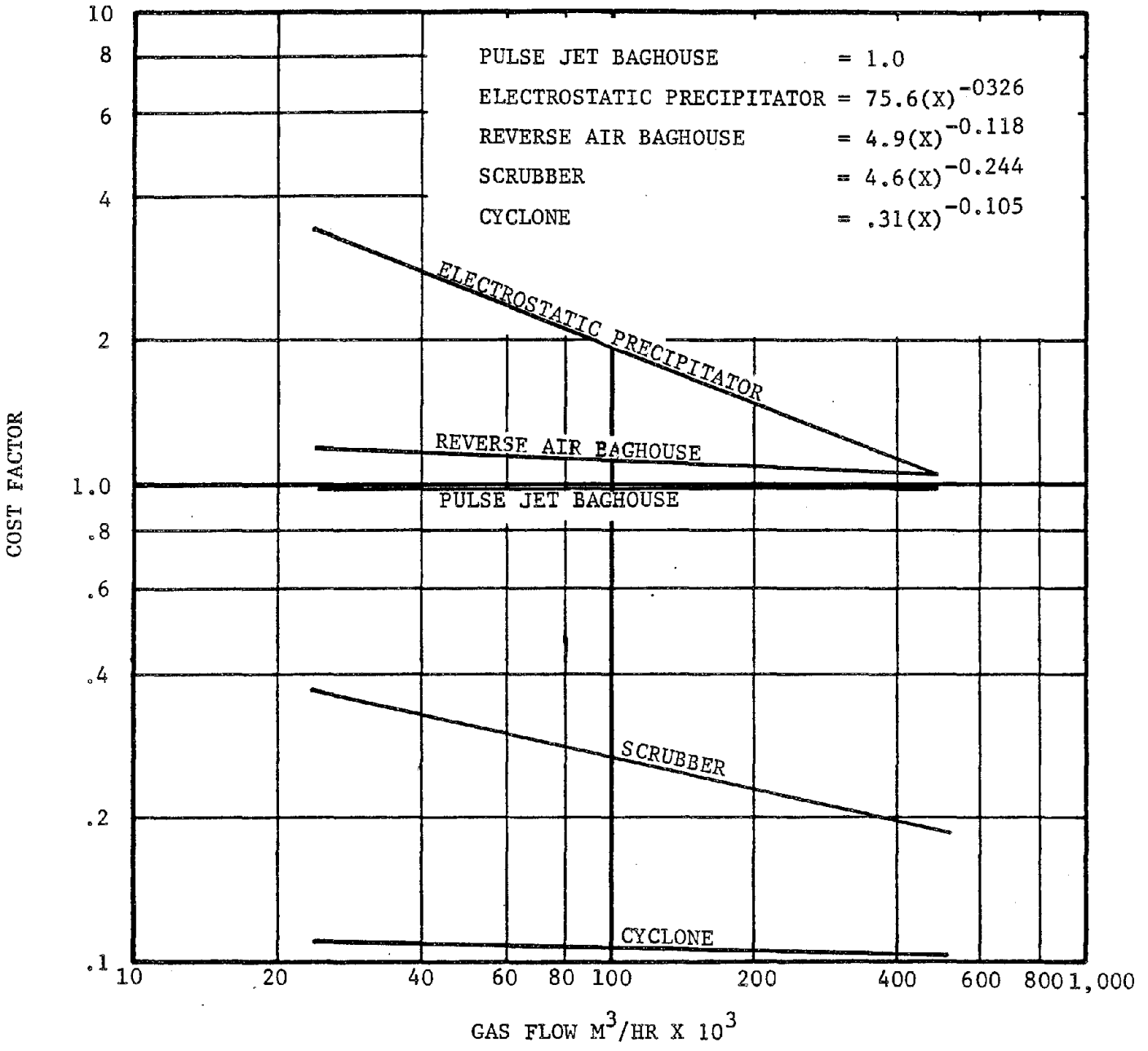
The cost of a pulse jet baghouse was then taken as a baseline cost. For a specific gas flow rate, the cost of each of the alternative equipment such as precipitator, reverse air baghouse, scrubber and cyclone was divided by the baseline pulse jet baghouse cost to obtain a cost factor. The cost factor was calculated as above for all the selected gas flow rates. Thus, a series of cost factor curves were obtained as shown.

TABLE 6

AIR POLLUTION CONTROL TEHNOLOGY

Group of Countries	Storage and Materials Handling
Group I	
U.S.A., Canada, Japan	Pick-up hoods on transfer points and evacuation systems. Baghouse for particulate control
Group II	
Europe, Scandinavia, Australia, New Zealand, Taiwan	Pick-up hoods on transfer points and evacuation system. Venturi scrubber (medium pressure for particulate control.
Group III	
Brazil, Argentina, Mexico, Venezuela, Guayana, Jamaica	Pick-up hoods and evacuation system. Venturi (wet) scrubber for particulate control.
Group IV	
Ghana, Guinea, Egypt, Turkey, Bahrain, Algeria, Indonesia, India, Surinam	Pick-up hoods & evacuation system. Multi-clone for particulate control.

TABLE 7



3.3.3. EMISSION CONTROL SYSTEMS COST FACTORS

SCALE–LOGARITHMIC

3.4. CAPITAL COSTS CALCULATION - UNITED STATES LOCATION

3.4.1. DIRECT CONSTRUCTION COSTS

The direct construction costs are provided for each of the refinery unit process areas and general facilities. The costs are represented by formulae and equivalent curve on a log graph for the range of capacities indicated. The costs are subdivided into the following components for each unit process: labor, materials, equipment usage and equipment.

Labor costs are based on labor rates and labor productivity prevalent in the mid-United States in 1984. An average wage rate of $32.21 per hour has been utilized with this rate divided into a base wage of $14.91 per hour with 60% burden and 35% construction indirect costs included. The 50% burden represents the cost of fringe benefits. The construction indirect costs include such items as permits, licenses, survey and layout, field organization, bonds-insurance fringe expenses, temporary buildings and facilities, temporary protection, temporary services, telephone and telegraph, blueprints-stationary and cleanup.

3.4.1.1. TRANSPORT COSTS

Freight costs for transport of materials and equipment to the jobsite are calculated to be 6 percent of the purchased equipment and material cost. This cost is additive to direct construction costs provided in the unit process cost sections. Ocean freight for sites located outside of the United States is calculated to be 15% of imported material and equipment. Refer to Section 3.5.

3.4.1.2. SALES TAX

The sales tax on materials and equipment for the mid-United States facility is calculated to be 2% and is additive to the sum of direct construction costs detailed in the unit process area cost sections.

3.4.1.3. IMPORT DUTIES

All purchases for the facility are assumed to be acquired in the United States for the United States location.

3.4.2. INDIRECT COSTS

Indirect costs, as described in this capital cost estimating system, consist of construction management and engineering supervision and procurement services. These costs vary with the size of the facility and are represented by the cost curve and formulae provided in this section.

3.4.2.1. CONSTRUCTION MANAGEMENT

Construction management costs consist of on-site functions to maintain control of quality, schedule, costs and orderly control of construction of the facility. The various disciplines involved are: project manager, engineering manager, administrative manager, purchasing manager, accounting manager and planning manager. Also, field engineers, site managers, inspectors, materials control personnel, accountants, warehousemen, expeditors, medical personnel, buyers, security and office personnel are included, plus field office operating expenses.

The costs also include relocation costs for certain personnel.

3.4.2.2. ENGINEERING, SUPERVISION AND PROCUREMENT

Engineering, supervision and procurement costs are associated with salaries and wages for: administration of the project, project engineering, planning and cost control, purchasing and expediting, office services, support services and design engineering. These costs include payroll additives for burden and overhead.

Expenses are allocated for personnel relocation and office expense as required.

3.4.3. OTHER COSTS

Associated with the cost of a project are expenses that, in many cases, are incurred as an owner's cost and are accounted for in this manner. These are included in this estimating system and itemized separately to allow the handbook user to assign these costs as required by the specific circumstances. A major cost that is omitted, however, is the cost of land which will vary in every analysis.

3.4.3.1. SPARE PARTS

Spare parts are expensed at the time of equipment purchase. The quantity of spare parts for any piece of equipment generally consists of one-year's supply. This cost is calculated to be 2.5% of the total construction cost. In remote locations, this value should probably be doubled to provide a two-year's supply.

3.4.3.2. MOBILE EQUIPMENT

Mobile equipment, including payloaders and forklifts utilized for process purposes, are included in the Unit Process Estimates. In addition, the facility requires payloaders, sweepers, flatbed trucks, pickups, station wagons, an ambulance, fire trucks, dump trucks, mobile cranes (50 tonne),

mobile cranes(15 tonne), portable air compressors, track mobiles and a locomotive. This equipment is estimated at $5,000,000.

3.4.3.3. OFFICE, SHOP AND LABORATORY EQUIPMENT

The cost of office, shop and laboratory furniture and equipment is estimated to be $2,500,000.

3.4.3.4. STARTUP EXPENSES

Startup expenses are divided into the following categories: training, startup organization, materials, and production delays.

Training of personnel, including supervisory and operating and maintenance personnel, may commence 1 year prior to the estimated startup of the plant. Supervisory personnel may be brought on site 2 years in advance.

The startup organization, in the ideal situation, would consist of an experienced operating crew working on 12-hour shifts to complete the training of personnel and startup of the facility. The duration is estimated to be approximately six months, at which time the number of startup personnel would be reduced to specific skill requirements for certain functions.

A number of vendor representatives are required to check-out equipment and ensure the equipment is assembled and started-up properly. These would include representatives for:

Power Plant
Instrumentation
Grinding Mills
Fan/Blowers/Compressors
Calcination Plant
Process Equipment

and would require a duration of one to three months.

Also, costs are incurred for modifications, abnormal equipment failures and miscellaneous circumstances. Costs are subdivided as follows:

Startup Costs	$13,000,000
Startup Organization	$23,000,000
Vendor Assistance	$ 1,000,000
Technical Services	$22,000,000
Miscellaneous	$41,000,000

Loss of production during the startup may vary considerably during the startup period. The delays depend greatly on the

skills and presence of an experienced startup team, the skills of the owner operator in learning to operate and maintain the equipment and the handling of process problems that may or may not be a known variable, depending on the amount of prior testwork or pilot plant work.

These costs are not included within the facility cost but should be accounted for when considering the economic viability of a project. Historical data is presented in Section 3.5 in the form of other experience.

3.4.3.5. OWNERS STAFF

The owners staff would generally consist of project and process personnel to prepare the project criteria, establish parameters, feasibility, location, raw material source, labor supply, testwork and technical approach to the project. This may require two years or more of preparation, with three years devoted to the construction of the facility and involvement in the startup and shakedown period.

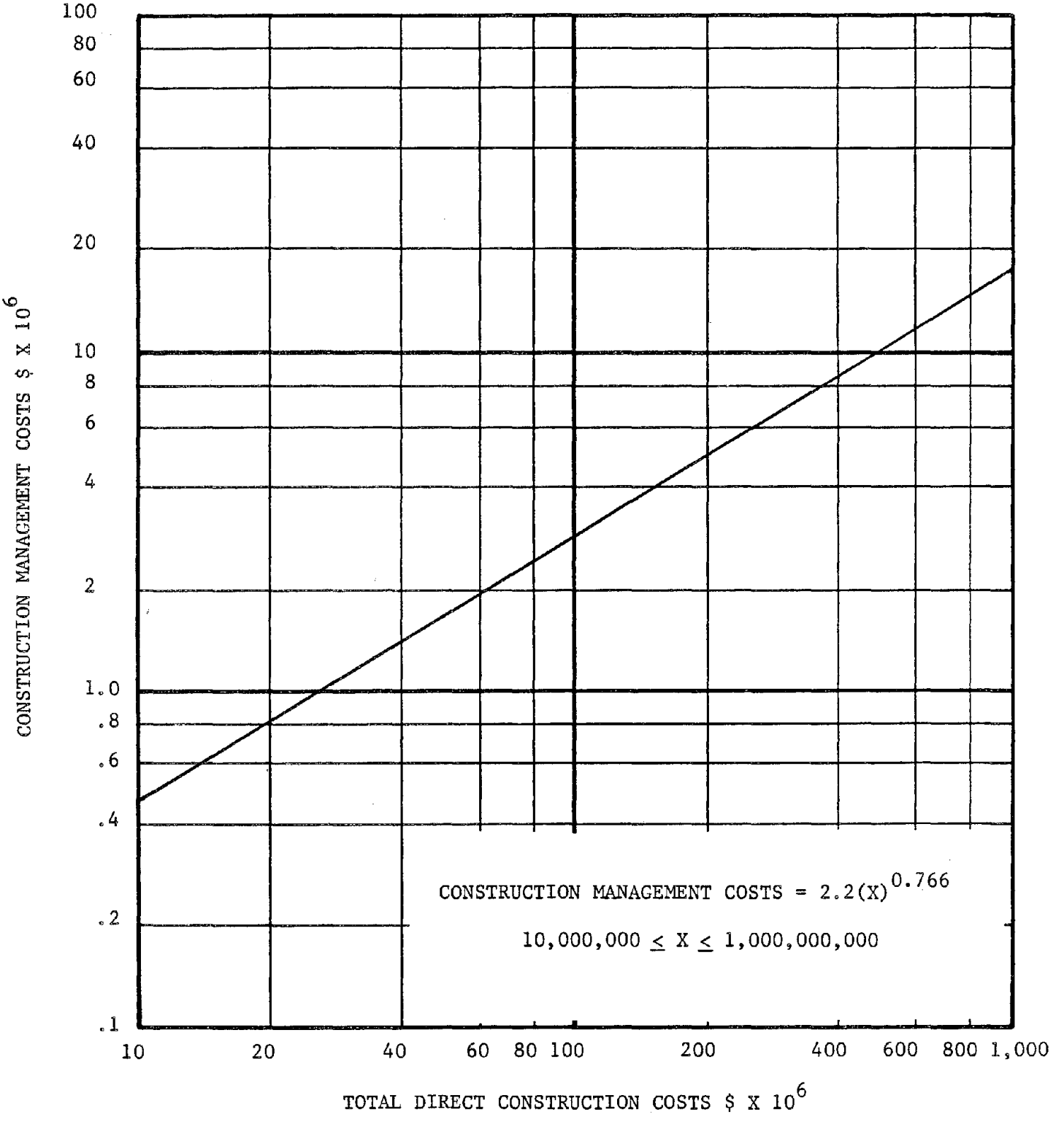
Major personnel would consist of the project manager, process/project engineers, mechanical engineer, electrical engineers and an office staff. This group does not include the owners operating staff, which will asssemble prior to the startup period. This cost should be included as an operations expense, and as with production, delays as part of an economic analysis of a greenfield plant.

The owners staff, including site visits for technical purposes and operation of the project, would require an estimated $5,000,000.

3.4.3.6. MISCELLANEOUS COSTS

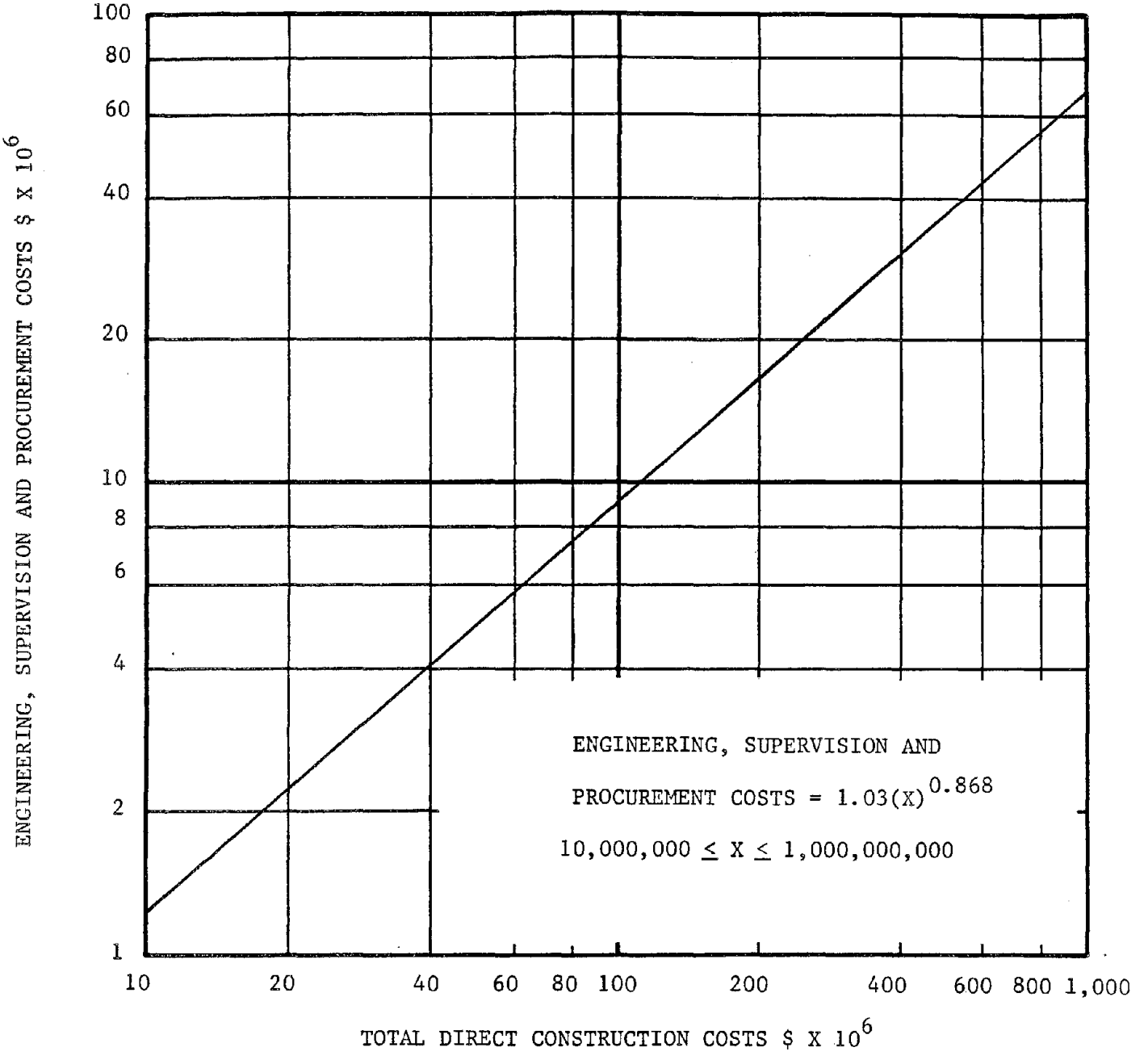
Miscellaneous costs include marketing studies, site selection, borehole testing, soils surveys, water supply studies and testing, environmental impact reports, process testing and feasibility studies. The estimated costs for an alumina refinery are estimated to be $41,000,000.

Technical assistance and fees are estimated to be an additional $22,000,000.



3.4.2.1. CONSTRUCTION MANAGEMENT

SCALE—LOGARITHMIC



3.4.2.2. ENGINEERING, SUPERVISION AND PROCUREMENT

SCALE–LOGARITHMIC

3.5. TRANSLATION OF CAPITAL COST METHODOLOGY -- A FACTOR APPROACH

The basic method used for estimating capital costs for alumina refining facilities in foreign locations, given cost estimates for an equivalent United States facility, is through a series of cost conversion factors (CCF). The CCF is defined as the ratio of the cost (expressed in United States dollars) in the country of interest to that in the United States. Thus, for example, if the CCF were numerically equal to 1.2 and the estimated United States cost were $10 million, the estimated cost (in United States dollars) of the foreign facility would be 1.2 (10) or $12 million.

Analysis of the various cost elements that comprise the total cost indicates that the CCFs are not constant, but rather vary by cost category. Thus, for example, construction labor costs in Surinam in 1983 were only about 36% of those in the United States even when productivity differences (discussed later) are taken into account, but materials costs in the same year were higher by a factor of nearly 1.3 compared to those in the United States. For this reason it is convenient to disaggregate the total capital cost into various components, e.g., labor, materials, etc., and to provide separate CCFs for each of the cost components. Operationally all that is involved is to apply the appropriate CCF to each of the component costs of the United States plant to calculate the estimated capital costs in the country of interest. These costs are then added to produce an estimated total cost in the foreign location.

The reader will note that it is possible in principle to calculate an overall CCF as the appropriately weighted combination of the individual CCFs. This overall CCF could then be applied to the estimated total capital cost of the United States plant to calculate the required cost in the country of interest. Such a procedure is described at the end of this section. It represents a convenient, though only approximate, calculation procedure. This procedure is only approximate because it must assume a "nominal" or base case plant of fixed configuration in order to calculate the appropriate weights to be applied to the individual CCFs to calculate the overall CCF. If the actual plant under analysis includes a different mix of unit processes than the base case, then some error is introduced into the resulting estimate. A more exact estimate can be prepared if the CCFs are applied at a disaggregated level.

In this study, six major component cost categories have been designated. These elements and their average percent of total capital cost of a typical United States facility are:

(a) Construction labor (23% of total) - costs include straight wages, burden, and indirect field costs. These factors compare construction wage rates in foreign countries with those in the United States and, at the same time, reflect differing levels of construction labor productivity.

(b) Construction materials (23% of total) - cost factors compare the weighted costs of structural steel shapes, reinforcing steel bar (rebar), Portland cement, lumber, gravel and crushed stone, and sand. These materials were selected because aggregate construction materials costs track well with these indicator materials.

(c) Equipment purchase (29% of total) - cost factors compare (1) the costs of equipment such as storage bins, belt feeders, conveyors, crushers, mixers, pumps, cyclones, furnaces, and filters that are utilized in the actual operation of the facility, (2) the sum of costs incurred in the transport of equipment to a port facility in the exporting country, the cost of ocean freight and the cost of transport within the importing country, and (3) the costs of any duties assessed on equipment imports. Transportation costs, i.e., specifically export country transportation costs and ocean freight, and import duties apply only to countries that import either all or part of their equipment needs.

(d) Equipment usage (8% of total) - cost factors compare costs of purchasing or renting on-site construction equipment such as bulldozers, cranes, haulage trucks, etc., that are utilized in the construction of the facility.

(e) Indirect costs (8% of total) - cost factors compare costs incurred in contractors construction management and engineering, supervision, and procurement (ES&P).

(f) "Other" costs (9% of total) - owners' costs, cost of spare parts, startup expenses and miscellaneous costs are compared in "other" cost factors.

The methodology described below enables the user to translate estimated United States costs to foreign locations. Numerical CCFs are provided in the following sections of the methodology discussion.

Before presenting an element-by-element discussion of the above costs, it is appropriate to venture some brief comments on the relevance of the respective cost shares given above to the accuracy of the "translated" cost estimate. In the typical United States plant, three cost elements--construction labor, materials and equipment purchase-account for an estimated 75% of the total capital cost. Because these costs need to be weighted by the appropriate CCFs, the aggregate cost share in the country of interest may vary from this figure. Nonetheless, in aggregate, the accuracy of these three cost elements are of key importance to the overall accuracy of the cost estimate because they account for such a large proportion of the estimated total cost.

In contrast, the remaining cost elements constitute, both singly and collectively, a relatively minor proportion of

total cost. Equipment usage, for example, is estimated to cost only about 8% of total capital costs. Even if this cost estimate were in error by as much as 50%, ceteris paribus, the overall capital cost estimate would be within about 4.0% of the true value.

For this reason, considerably more effort has been expended in the preparation of accurate CCFs for the first three cost categories in comparison to the remainder.

3.5.1. TRANSLATION OF CONSTRUCTION LABOR COSTS

Construction labor accounts for a large share, about 23% of total costs of a United States plant. Construction labor costs for the United States base-case plant include wages paid to workers, together with additional costs figured at a burden rate of 60%, and indirect field costs calculated at 35% of wages plus burden. In this study, burden and indirect field costs in foreign countries are also assumed to be approximately equivalent (in percentage terms) to those in the United States. Construction CCFs are the product of two terms,

(a) a relative wage ratio factor--this is the ratio of the hourly in construction wage in the country of interest to that in the United States. In Jamaica, for example, the average wage rate factor (shown in column 5 of Table 8) is 0.10-Jamaican construction wages in 1983 were only about 10% of those in the United States.

(b) a productivity factor--this is defined as the ratio of average labor input required in the country of interest to that in the United States. For Jamaica, approximately 2.63 times as many labor hours are required for a given construction task than would be required in the United States, as shown in column 8 of Table 8.

The relative construction labor cost for a facility built in 1983 in Jamaican is thus estimated as 0.10 (2.63) or 0.26, the CCF shown in column 9 of Table 8.

Analysis of wage and productivity data indicates that countries with lower wage rates than the United States also have lower productivities. Thus these countries do not enjoy quite the labor cost advantage that a simple comparison of wage rates would indicate. Productivity differences arise in part because United States workers are better trained, healthier, etc., but also because of the availability of labor saving equipment, improved logistics arrangements, etc. The generally higher wages paid to United States workers both reflects their intrinsic productivity and acts to spur substitution of capital for labor, both of which result in higher physical productivity.

Table 8 provides all of the information needed to translate construction labor costs to foreign locations. Column 1 of the table lists all of the market economy countries that house (as of this writing) alumina refining facilities. Column 2 provides 1980 wage rates for construction workers in these countries. Column 3 provides wage rate data for 1983. The rates are obtained (for most countries) 1/ by escalating 1980 construction wages using a construction wage index. The user should bear in mind that wage rate estimates are based on national averages in the respective countries (though in some countries data from only one or a few cities is used by their government for statistical purposes) and these averages can conceal substantial intra-country variability. Site-specific data should be used if available.

Column 4 of Table 8 provides hourly wage data with an adjustment for burden and indirect field costs. The adjustment for each country is 1.60 for burden, indicating burden to be 60% of the direct wage, and 1.35 for indirect costs, indicating the latter to be 35% of the sum of direct wages and burden. These uniform adjustments are made necessary by the lack of reliable country-specific information on burden and indirect labor costs for all countries of interest 2/. Based upon data from a sample of the countries, it is concluded that the error introduced by this assumption is less than 25%.

Column 5 shows the ratio of wages in the host country to those in the United States. Since burden and indirect cost adjustments are assumed to be the same for all countries, column 5 also shows the ratio of the sum of wages, burden and indirect costs in the host country and the same in the United States. The ratio is presented here because it is used to calculate foreign productivity factors (see column 6). Column 7 provides productivity factors calculated via an alternative approach, i.e., one using ratios of Gross National Product per capita in the various countries. Figures in column 8 are the average of the figures in columns 6 and 7 and are used as the requisite productivity factors. Finally, column 9 provides the overall

---

1/Phoenix Associates have not developed indices for the United States. Construction wages were obtained by escalating 1980 wages by the Engineering - News Record construction wage index.

2/Part of the reason for this difficulty is that there are not uniform statistical standards for classification of "fringe benefits" among the various countries that provide these data. One man's base is literally another's fringe. In Japan, for example, substantial bonuses are paid to workers annually. The Japanese view this bonus as virtually automatic and a normal component of income. In the United States these would be classified as a fringe benefit. Such differences of statistical convention greatly complicate the task of developing meaningful country-specific burden rates.

TABLE 8. - Wage rates, productivity factors and construction labor conversion factors - 1983

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
					Productivity factors			
Country	1980 Wage rate,[1] $U.S./h	1983 Wage rate,[2] $U.S./h	1983 Wage burden and indirect costs,[3] $U.S./h	Ratio of 1983 wages, U.S.=1.00	From wage ratio,[4] U.S.=1.00	From GNP per capita,[5] U.S.=1.00	Average, U.S.=1.00	Conversion factor, U.S.=1.00
Australia	5.65	6.05	13.07	0.47	1.27	1.06	1.17	0.55
Brazil	0.69[6]	0.53	1.14	0.04	5.76	1.94	3.85	0.15
Canada	10.36	13.44	29.03	1.08	0.99	1.04	1.02	1.06
France	5.41	4.49	9.70	0.35	1.44	1.07	1.26	0.44
Ghana	0.85[7]	1.24	2.68	0.09	4.85	5.58	5.22	0.26
Greece	3.91[6]	3.71	8.01	0.29	1.57	1.43	1.50	0.44
Guinea	0.37[7]	0.39[8]	0.84	0.03	7.24	5.58	6.41	0.19
Guyana	0.86[6]	0.95	2.05	0.07	3.77	3.83	3.80	0.27
India	0.35[6]	0.36	0.78	0.03	7.24	5.87	6.56	0.20
Ireland	4.72	4.30	9.29	0.33	1.48	1.34	1.41	0.47
Italy	5.31	4.91	10.61	0.38	1.39	1.22	1.31	0.50
Jamaica	1.17[7]	1.31	2.83	0.10	2.94	2.32	2.63	0.26
Japan	6.36	7.10	15.34	0.55	1.20	1.08	1.14	0.63
Norway	9.79	8.72	18.84	0.68	1.12	1.00	1.06	0.72
Spain	3.57	3.27	7.06	0.25	1.70	1.34	1.52	0.38
Surinam	2.36[7]	2.87	6.20	0.22	1.81	1.49	1.65	0.36
Taiwan	2.19[6]	1.92	4.15	0.15	2.26	1.66	1.96	0.29
Turkey	0.59	0.46	0.99	0.04	5.76	2.38	4.07	0.16
United Kingdom	5.99	5.23	11.30	0.41	1.35	1.11	1.23	0.50
United States	9.98	12.89	27.84	1.00	1.00	1.00	1.00	1.00
West Germany	7.72	6.36	13.74	0.49	1.25	1.05	1.15	0.56
Venezuela	2.55[9]	2.95	6.37	0.23	1.77	1.41	1.59	0.37
Yugoslavia	1.52	0.95	2.05	0.07	3.77	1.69	2.73	0.19

[1]Data obtained from International Labor Organization, Yearbook of Labor Statistics, various editions, unless otherwise noted.

[2]1980 wages were escalated to 1983 levels using the Phoenix construction wage index, with the exception of Guinean and US wages because Phoenix does not maintain indices for these countries. The 1983 wage for Guinea were predicted, see footnote 8. US wages were escalated to 1983 using the Engineering News Record construction wage index.

[3]Assuming a burden level of 60% of the basic wage and indirect costs equal to 35% of the sum of the basic wage and burden.

[4]Estimated from the equation,

$$PF_i = 0.283\ r^{-0.895} + 0.717$$

where

PF_i = productivity factor in country i, and

r = ratio of host country and U.S. wage.

[5]Estimated from the equation,

$$PF_i = 0.283\ (\text{Ratio}_{\text{GNPCAP}})^{0.727} + 0.717$$

where

PF_i = productivity factor in country i, and

$\text{Ratio}_{\text{GNPCAP}}$ = ratio of GNP per capita in host country and GNP per capita in the United States.

[6]Data obtained from Engineering News Record, June 1980, p. 96.

[7]Predicted from the equation,

$$w_i = 0.00376\ (GNPCAP_i)^{0.8128}$$

where

w_i = construction wage in country i, and

GNPCAP = 1980 GNP per capita in country i, ($US).

[8]Predicted from the equation given in footnote 7 but substituting 1983 GNPCAP for 1980 GNPCAP.

[9]Data obtained from Engineering News Record, December 1980, p. 93.

labor conversion factor needed to translate to other countries. It is obtained by multiplying the figures in column 5 by those in column 8 3/.

Column 9 contains the key numbers for cost translation. Figures in this column are the CCFs needed to translate labor costs associated with the United States base-case plant to those in another country. United States labor costs, obtained from appropriate cost curves provided in other sections of this handbook, are multiplied by the appropriate factor located in column 9. The result is the estimated cost of construction labor in the host country. If the user of the handbook is able to obtain reliable country or even site-specific information on wage or burden rates, indirect costs, or the worker productivity, the methodology can be adjusted to accommodate this information in lieu of the estimates given in Table 8. If, for example, the burden adjustment for some country "X" were known to be 65% rather than the 60% assumed here, then the cost factor can be adjusted to reflect this knowledge by multiplying the CCF given in column 9 by the ratio 1.65/1.60. Similarly, if it is learned that indirect costs in the country of interest are not 35% of the sum of direct wages and burden but rather, say 50%, then it is necessary to multiply by a factor of 1.50 rather than 1.35--hence the appropriate cost factor is the table entry in column 9 of Table 8 multiplied by (1.65/1.60) times (1.50/1.35). In this way, users of the handbook can incorporate available country--or site-specific information to the methodology given here.

3.5.2. TRANSLATION OF CONSTRUCTION MATERIALS COSTS

A comparison of international prices for construction materials, represented by structural steel shapes, reinforcing steel bars (rebar), portland cement, gravel and crushed stone, lumber, and sand, results in the various foreign materials CCFs given in column 5 of Table 9. These factors are derived from 1980 prices in the foreign countries weighted to reflect their contribution to total alumina plant material costs (see column 2). These weights reflect the assumption that 52% of the total materials cost is accounted for by structural steel shapes; 7% is accounted for by rebar; 4% (each) is attributable to cement and lumber; 5% is made up of gravel/crushed stone costs; and the remaining 1% is attributable to sand--percentages selected on the basis of RKE's historical experience.

Approximately 27% of the outstanding construction materials costs is made up of "other" construction materials costs consisting of equipment installation materials (18%) and electrical

---

3/Alternatively, labor conversion factors can be derived by multiplying the 1982 wage rate (with or without adjustments for burden and indirect costs) in the country by the productivity factor for the country, then dividing the result by the 1983 wage rate (with or without adjustments) in the United States.

TABLE 9. - Construction materials cost factors - 1983

(1) Country	(2) Weighted cost 1980, million $U.S.	(3) Price change 1980-1983, pct.[1]	(4) Weighted cost 1983, million $U.S	(5) Conversion factor, U.S.=1.00
Australia	56.216	-1	55.653	1.01
Brazil	56.694	-14	48.757	0.89
Canada	50.760	17	59.389	1.08
France	48.486	-24	36.849	0.67
Ghana	52.751	-	-	-
Greece	57.470	-18	47.125	0.86
Guinea	52.751	-22	41.146	0.75
Guyana	64.548	-9	58.739	1.07
India	54.134	13	61.171	1.11
Ireland	71.475	-19	57.895	1.05
Italy	78.709	-27	57.458	1.04
Jamaica	64.548	12	72.294	1.31
Japan	45.454	-9	41.363	0.75
Norway	55.553	-16	46.665	0.85
Spain	43.545	-18	35.707	0.65
Surinam	64.548	12	72.294	1.31
Taiwan	68.744	-14	59.120	1.07
Turkey	42.554	-25	31.916	0.58
United Kingdom	70.355	-18	57.691	1.05
United States	56.205	-2[2]	55.081	1.00
West Germany	61.560	-26	45.554	0.83
Venezuela	40.092	31	52.521	0.95
Yugoslavia	33.342	-38	20.672	0.38

[1]Price changes refer to percent change in local currency; based on Phoenix construction materials indices unless otherwise noted.

[2]Although the computer printout of ENR prices of construction materials shows a 23% increase between 1980 and 1983 a comparison of actual 1980 and 1983 data--the first based on the average of quarterly data and the latter based on the average for June--shows a decrease of 2.0% in the price of construction materials of interest. Compare:

Average 1980 prices		June 1983 prices
$630/MT	Structural Steel	$621/MT
$418/MT	Rebar	$383/MT
$65/MT	Portland Cement	$68.21/MT
$14.30/Cubic Yard	Gravel/Cr. Stone	$15.43/Cubic Yard
$11.40/Cubic Yard	Sand	$11.90/Cubic Yard
$137/Cubic Meter	Lumber	$142/Cubic Meter

Based on this evidence the 1980 US weighted cost was deflated by 2% rather than inflated by 23%.

equipment (9%). To the extent that these costs, foremost equipment installation materials, are likely to track with an aggregate of six materials referenced above, the error introduced by their omission is small.

Weighted costs in 1980 are then escalated to 1983 levels (see column 4) using (with certain exception) 4/ the Phoenix Associates construction materials cost indices for the respective countries. Finally, the CCFs are calculated by dividing the 1983 weighted costs in the host countries by that in the United States. These factors are given in column 5 of the table. As with labor cost data materials costs in foreign locations are taken from data sources that may represent only a few cities in the country of interest. These costs may be expected to be higher in locations far from major industrial centers, particularly in Third World countries. Again, site-specific costs should be used if available.

The factors in column 5 are used for translating materials costs from the United States base-case plant location to locations abroad. United States materials costs, which are obtained from appropriate cost curves provided in earlier sections of this handbook, are multiplied by the appropriate CCF located in column 5. The result is the estimated cost of materials in the country of interest. Because several of the materials used in this index (e.g., steel rebar) are internationally traded, the user may wonder why there is so much variability in the estimated CCFs. It is important to note that these are "heavy" in relation to unit value, and thus transportation costs can contribute significant variability to these costs. Also important are various tariff and non-tariff trade barriers that affect prices. Additionally, sand and gravel are usually locally produced and cost differences can arise as a result of local availability, transportation costs and other factors. Finally, exchange rates affect the relative prices (when expressed in United States dollars). There are, of course, market forces at work acting to produce an equilibrium among the exchange rates of the countries of the world. Nonetheless, governments control exchange rates (in the short term at least) and these policies can lead to distortions in relative factor prices. Chile, for example, maintained an official exchange rate of 39 pesos per United States dollar in 1980, 1981, and the first quarter of 1982, even though most economists believed the peso was overvalued for part of this time period. Indeed, the rate increased to 73.4 pesos per United States dollar by the last quarter of 1982. Exchange rate fluctuations can substantially alter relative prices.

4/As with construction wages, Phoenix Associates do not maintain construction materials cost indices for the United States. United States weighted costs were advanced on the basis of Engineering News Record data for June 1983.

For these reasons, relative prices for the same commodity in different countries can vary substantially at a point in time.

To illustrate the use of these factors, assume that the estimated material costs at the United States plant are $10 million, and that this cost must be translated to Jamaica. From Table 9, the appropriate cost factor for Jamaica is given as 1.31. Thus, the estimated materials cost in Jamaica is 1.31 (10) or $13.1 million.

3.5.3. TRANSLATION OF EQUIPMENT PURCHASE COSTS

Equipment purchase refers to the equipment, such as crushers, feeders, conveyors, pumps, etc., that is used in the actual operation of the plant. For the purposes of this translation methodology, it is assumed that most countries are able to produce part or all of their equipment needs. Only Ghana is assumed to import all of its equipment. Several other countries, e.g., Guinea, Guyana, Ireland, Jamaica and Surinam are assumed to import 90% or more of their equipment needs. It is also assumed that the costs for any equipment produced in-country are approximately equal to those if purchased in the United States. For example, Venezuela is estimated to produce about 40% of its equipment needs domestically and thus the cost of this equipment is approximately equal to the cost of the same equipment produced elsewhere. However, the remaining 60% of equipment--i.e., imported equipment--may be more expensive than that in the United States due to added costs incurred in transportation and payment of any applicable import duties. In sum, costs of equipment produced domestically are assumed equal; however, differences in equipment purchase costs-which are reflected in the foreign equipment cost factors--arise as a result of the need to import part or all of the equipment needed and, in addition, the import duties that are assessed upon these imports.

Table 10 provides necessary data for calculating equipment cost factors for all of the market economy countries presently housing an alumina facility. Column 1 lists all of the relevant countries. Columns 2 and 3 provide estimates of the percentage of a country's equipment needs that can be produced in-country and, derivatively which must be imported from abroad. Columns 4-6 show the cost of transportation as a percent of equipment cost. As illustrated, transportation costs are broken down into 3 categories: cost of transportation within the exporting country, i.e., the cost of moving equipment from the factory or warehouse to a port facility; the cost of ocean freight; and the within-country cost, i.e., the cost of moving equipment from one location to another or, in the case of an importing country, the cost of moving the equipment from the receiving port to some inland location. Based on historical experience, percentages of 6%, 15%, and 6%, respectively, were selected. Within-country transportation costs are incurred by all countries while

TABLE 10. - Salient data for calculating equipment cost factors

Country	Equipment produced in-country, percent	Equipment imported, percent	Transportation costs: Export country, percent	Transportation costs: Ocean freight, percent	Transportation costs: Within-country, percent	Applicable rate of import duty, percent	Conversion factor, U.S.=1.00
Australia	80	20	6	15	6	10	1.07
Brazil	75	25	6	15	6	45	1.19
Canada	100	0	-	-	6	-	1.00
France	100	0	-	-	6	-	1.00
Ghana	0	100	6	15	6		
Greece	50	50	6	15	6	5	1.14
Guinea	5	95	6	15	6	5	1.26
Guyana	5	95	6	15	6	8	1.29
India	70	30	6	15	6	40	1.21
Ireland	5	95	6	15	6	-	1.20
Italy	85	15	6	15	6	-	1.03
Jamaica	10	90	6	15	6		
Japan	100	0	-	-	6	-	1.00
Norway	90	10	6	15	6	-	1.02
Spain	60	40	6	15	6	15	1.16
Surinam	5	95	6	15	6	3	1.23
Taiwan	90	10	6	15	6	-	1.02
Turkey	20	80	6	15	6	5	1.22
United Kingdom	100	0	-	-	6	-	1.00
United States	100	0	-	-	6	-	1.00
West Germany	100	0	-	-	6	-	1.00
Venzuela	40	60	6	15	6		
Yugoslavia	75	25	6	15	6	12	1.09

transportation costs within an exporting country and ocean freight costs are incurred only by countries that import part or all of their equipment needs.

Column 7 provides applicable rates of import duties on equipment used in alumina refineries. As with export country transportation costs and ocean freight costs, import duties are applied only to the countries that import equipment. Countries that import only a share of their equipment needs incur transportation and import duty costs only on that share that is imported. Some countries, e.g., Canada, France, Japan, United Kingdom, United States and West Germany, are assumed to be totally self-sufficient in equipment and thus incur no additional costs other than within-country transportation costs.

Handbook users should be aware that import duty concessions can sometimes be individually negotiated with host governments of development nations--particularly if the proposed facility is estimated to make a substantial contribution to the local economy. These situations obviously cannot be reflected in the factors given here, but should be considered in any site-specific analysis.

Equipment costs for the United States base case plant--obtained from appropriate cost curves--do not reflect within-country transportation costs, and therefore these must be adjusted by multiplying by a factor of 1.06, indicating a within-country transportation cost equal to 6% of equipment costs. Since it is assumed that equipment costs produced within-country are equal and that within-country transportation costs are also equal (i.e., 6%), countries that produce all of their equipment domestically have cost factors of 1. These are shown in column 8. Factors for other countries are also shown in column 8. All of the factors are calculated on the assumption that United States equipment costs have been adjusted to reflect within country transportation costs.

To translate equipment costs to foreign locations, the user of the handbook should first obtain the cost associated with the United States base case plant--obtained from appropriate cost curves. Next the United States cost should be adjusted to reflect within-country transportation costs, i.e., by multiplying it by a factor of 1.06. . Finally, the appropriate country factor listed in column 8 of Table 10 is multiplied by this transportation-adjusted cost. The net result is the equipment cost, including, where relevant, export country transportation costs, ocean freight costs, within-country transportation costs, and import duty costs, in the foreign country of interest.

3.5.4. TRANSLATION OF EQUIPMENT USAGE COSTS

As noted above, the following cost categories are of substantially lesser importance in terms of their contribution to total costs. These include equipment usage costs, indirect costs and "other" costs.

Equipment usage refers to construction equipment (e.g., bulldozers, cranes, trucks, etc.) that is purchased or rented at the construction site and utilized only during the construction phase of the facility. For a typical alumina plant constructed in the United States, these costs account for only about 8% of total capital costs. Thus precise estimation of this cost element is not critical to the overall accuracy of estimates. If, for example, this cost estimate were in error by 50%, the overall cost estimate would be in error by only 4.0%.

There is little reliable information on which to base CCFs for this cost element. The recommended CCFs for all countries is unity, though obviously if the handbook user has specific data available, these should be used in lieu of the default CCFs suggested here.

Some earlier studies of construction costs have ventured the following assumptions for computation of these CCFs:

(a) To a first approximation, equipment rental rates are roughly constant throughout the world.

(b) But, construction labor productivity is lower in most countries compared to the United States, as shown, for example, in column 8 of Table 8.

(c) Thus, the appropriate CCFs are in fact the labor productivity factor in country "X" were 2.0, the CCF would also be 2.0 because the equipment would have to be rented for twice the time.

Ultimately this approach was rejected here--in part because productivity differences, while real, do not translate directly into operating time differences in the manner suggested in (c) above. Rather, productivity differences can be reflected in differences in crew size with less than proportional time stretch-outs. Secondly, the mix of construction equipment used in another country may not match exactly that used in the United States (indeed, this accounts in part for productivity differences)-and, in fact, may be less costly to rent in other countries.

3.5.5. TRANSLATION OF INDIRECT COSTS

As defined in other sections of this handbook, indirect costs refer to costs incurred in contractors field indirects, construction management and engineering, supervision and procure-

ment. An analysis of these types of costs indicates cost to be related to the composition of management, design and the engineering services staff, in terms of expatriate and local labor.

Based on analyses of current practice and expected future developments, the size of managerial, design and ES&P staff made up of expatriate labor is diminishing. The greatest contributing factor in this, clearly, has been the emergence of indigenous engineering firms with considerable skill and expertise, especially in regard to non-process type work, in countries that have previously been dependent upon expatriates from firms in the United States, Japan and Europe. Foreign firms that once provided managerial and technological expertise on a broad scale and for various skill levels are now required to provide the needed know-how for only a few of the key-discipline positions. The remaining positions are (and increasingly will be) filled by local talent and resources. As a result, the percentage share of managerial, design, ES&P staff made up of expatriates is (and will be) smaller than that which has historically been evident. The percentage share of expatriates given in Table 11 represents the most likely estimates based on this more recent analysis. In general, when management and ES&P personnel are provided from local resources, indirect costs are low, but when it consists in large part of expatriates then costs are high--conceivably higher than for the same job in a developed country(12). Costs are especially high when personnel have to travel to and from the plant site.

Table 11 provides estimated conversion factors for indirect costs associated with an alumina refinery. The factors are derived by estimating the share of expatriate and local labor employed in management and ES&P activities. Expatriates are assumed to earn wages and salaries equal to those earned by management and ES&P personnel in the United States. To account for wage premiums, housing expenses, transportation costs, and daily living expenses, expatriate labor costs are adjusted by 40%. This percentage reflects historical experience. Costs for local managers and ES&P personnel are calculated on the assumption that the ratio of salaries and wages between local and United States management and ES&P personnel (as well as productivity ratios) are the same as those between local construction workers and those in the United States.

To translate indirect costs from the United States base case plant, appropriate country conversion factors must be applied. Multiplication of the United States cost by the appropriate factor (column 6) results in an estimate of indirect costs in the foreign country of interest. An examination of column 6 indicates that indirect costs in most countries are less than the indirect costs in the United States. This is due largely to the difference in relative pay scales between managers and ES&P personnel in foreign countries and those in the United States. Since expatriates make up only a small share of managerial, design and ES&P labor--with the highest estimate being 30% in

TABLE 11. - Salient data for calculating indirect costs factors

Country	Estimated share of expatriate labor of management and ES&P personnel, percent	Estimated share of local labor of management and ES&P personnel, percent	Adjustment to expatriate labor, multiplying factor	Adjustment for local labor, multiplying factor	Conversion factor, U.S.=1.00
Australia	5	95	1.40	0.55	0.59
Brazil	10	90	1.40	0.15	0.28
Canada	0	100	1.40	1.06	1.06
France	0	100	1.40	0.44	0.44
Ghana	30	70	1.40	0.26	0.60
Greece	15	85	1.40	0.44	0.58
Guinea	30	70	1.40	0.19	0.55
Guyana	25	75	1.40	0.27	0.55
India	10	90	1.40	0.20	0.32
Ireland	5	95	1.40	0.47	0.52
Italy	0	100	1.40	0.50	0.55
Jamaica	30	70	1.40	0.26	0.60
Japan	0	100	1.40	0.72	0.72
Norway	0	100	1.40	0.38	0.48
Spain	10	90	1.40	0.38	0.48
Surinam	25	75	1.40	0.36	0.62
Taiwan	10	90	1.40	0.29	0.40
Turkey	10	90	1.40	0.16	0.28
United Kingdom	0	100	1.40	0.50	0.50
United States	0	100	1.40	1.00	1.00
West Germany	0	100	1.40	0.56	0.56
Venezuela	15	85	1.40	0.37	0.52
Yugoslavia	5	95	1.40	0.37	0.52

Ghana, Guinea and Jamaica--the additional costs incurred in employing expatriates are not so large as to increase total indirect costs beyond those incurred in the United States.

3.5.6. TRANSLATION OF "OTHER" COSTS

The final category in the summation of costs is referred to as "other costs" and includes the elements of owners costs, cost of spare parts, startup expenses, and miscellaneous costs. A preliminary analysis of startup expenses failed to show country specific variability. It is, therefore, suggested that costs be translated on a 1:1 basis. More important than the specific startup costs, however, is the loss of plant output occasioned by low-capacity utilization during the startup phase. Shown below are the estimated average capacity utilization at nonferrous smelters during the first four years following startup.

Year	% Capacity Utilization
1	38
2	62
3	76
4	85

It is recommended that these throughput factors be used to reflect average startup experience. Costs calculated on a cents per pound of metal basis will reflect these low initial rates of capacity utilization, and may be materially higher than costs calculated on the assumption of 100% utilization of capacity.

Startup cost estimates (included in "other" costs) relate to planned out-of-pocket costs for engineering personnel, materials, etc. These costs, however, do not consider the costs attributable to delays in reaching design capacity. Delays and reduced capacity output are costly for two reasons. First, delays directly reduce the present value of projected revenue streams associated with the scale of finished product. Second, operation at reduced capacity increases costs because fixed costs of operation are spread over a smaller output base. This latter effect is explored below.

Following the usual conventions, the total cost of production, TC, is represented as the sum of fixed costs, denoted by the symbol, FC, and variable costs defined below,

$$TC = FC + vCf \qquad (1)$$

where
- TC = total annual cost ($),
- FC = annual fixed costs ($),
- v = variable unit costs ($/unit),
- C = annual capacity (units/year), and
- f = fractional capacity utilization ($0 \leq f \leq 1.0$).

Now, let

$$\Psi = \frac{FC}{Cv}, \qquad (2)$$

equal the ratio of fixed costs to variable costs at full capacity utilization. Since smelting and refining are widely regarded as having large fixed costs in relation to variable costs, Ψ would be expected to exceed unity ($\Psi > 1$).

From (1) and (2) the average cost of production per unit, AC, is given by,

$$AC = \frac{Cv(\Psi + f}{Cf}, = v(\frac{\Psi}{f} + 1), \qquad (3)$$

and this is an increasing function of unit cost, the ratio of fixed to variable costs, and a decreasing function of capacity utilization. Thus, to the extent that capacity utilization is lower in the years immediately following startup, unit costs of production will be larger. This increase should legitimately be viewed as an added component of startup costs.

The average unit costs at "startup levels" of capacity utilization, f, relative to what it would be at design output (f = 1.0) is (from equation (3)),

$$R = \frac{(\Psi/f + 1)}{(\Psi + 1)}, \qquad (4)$$

where R is the relative unit cost ratio. For example, if $\Psi = 4$ and the startup level of capacity utilization is 50%, R = 1.80. Figure 6 shows a three dimensional view of how R varies with % capacity and Ψ.

Note that, except where f = 1.0 exactly, the relative unit cost ratio decreases with capacity utilization and increases with Ψ. Moreover, as can be seen from Figure 6, the cost penalties of low startup capacity utilization levels can be substantial. The variable ranges displayed in Figure 6 are realistic. As was noted above levels of capacity utilization in the first year of operation average only about 40% for nonferrous smelters. Even with values of Ψ as low as 2 to 3, the relative unit cost penalty can be of the order of a factor of 2 to 2.13. This difference becomes smaller as the facility's capacity utilization rate increases with operating experience.

3.5.7. TRANSLATION OF TOTAL PLANT COSTS

In Sections 3.5.1 through 3.5.6 foreign country cost factors are provided for 6 major categories of costs enabling the handbook user to translate the costs of a particular United States plant to various worldwide locations. An alternative and simpler

approach--which would facilitate the translation process--is to aggregate the cost factors for each of the 6 categories above into what is called a total plant factor. The application of total plant factors, however, assumes that all of the decision variables utilized in the construction of the United States base-case plant are held constant at the foreign location, and should not be used if the foreign plant is not identical to the United States base-case. The application of total plant factors, nonetheless, does have the advantage of providing a simpler means to translate costs. It may be suitable for an initial approximation to be followed up by a more disaggregated analysis in cases where the plant configuration differs from the "base-case" plant.

Total plant factors can be calculated on the basis of the equation,

$$F_j = \sum_{i=1}^{n} f_i^j k_i$$

where,

F_j = the total plant factor in country j,
f_i^j = the country factor for a cost category i, and
k_i = the percentage share of category i in relation to the total plant costs.

Based on details worked out for the United States base-case plant, with an annual capacity of 600,000 mt, utilizing Bayer technology including all refining steps and environmental equipment and excluding miscellaneous costs percentage shares of the major cost categories are as follows:

- construction labor - 23%;
- construction materials - 23%;
- equipment purchased (including transportation and duties) - 29%;
- equipment usage - 8%;
- indirect costs - 8%; and
- other costs - 9%.

On the basis of these percentage shares, total plant factors can be calculated for all the countries included in the analysis. These factors are given in Table 12.

In broad terms, all of the factors given in Table 12, with the exception of Canada, are less than unity indicating capital

TABLE 12. - Total plant cost factors - 1983

(1) Country	(2) Factor for construction labor U.S.=1.00	(3) Factor for materials U.S.=1.00	(4) Factor for equipment* U.S.=1.00	(5) Factor for equipment usage U.S.=1.00	(6) Factor for indirects U.S.=1.00	(7) Factor for other costs U.S.=1.00	(8) Total plant factor U.S.=1.00
Australia	0.55	1.01	1.07	1.00	0.59	1.00	0.89
Brazil	0.15	0.89	1.19	1.00	0.28	1.00	0.78
Canada	1.06	1.08	1.00	1.00	1.06	1.00	1.04
France	0.44	0.67	1.00	1.00	0.44	1.00	0.75
Ghana	0.26	-	-	1.00	0.60	1.00	-
Greece	0.44	0.86	1.14	1.00	0.58	1.00	0.85
Guinea	0.19	0.75	1.26	1.00	0.55	1.00	0.80
Guyana	0.27	1.07	1.29	1.00	0.55	1.00	0.90
India	0.20	1.11	1.21	1.00	0.32	1.00	0.85
Ireland	0.47	1.05	1.20	1.00	0.52	1.00	0.91
Italy	0.50	1.04	1.03	1.00	0.55	1.00	0.87
Jamaica	0.26	1.31	-	1.00	0.60	1.00	-
Japan	0.63	0.75	1.00	1.00	0.63	1.00	0.83
Norway	0.72	0.85	1.02	1.00	0.72	1.00	0.88
Spain	0.38	0.65	1.16	1.00	0.48	1.00	0.78
Surinam	0.36	1.31	1.23	1.00	0.62	1.00	0.96
Taiwan	0.29	1.07	1.02	1.00	0.40	1.00	0.81
Turkey	0.16	0.58	1.22	1.00	0.28	1.00	0.72
United Kingdom	0.50	1.05	1.00	1.00	0.50	1.00	0.86
United States	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
West Germany	0.56	0.83	1.00	1.00	0.56	1.00	0.82
Venezuela	0.37	0.95	-	1.00	0.52	1.00	-
Yugoslavia	0.19	0.38	1.09	1.00	0.25	1.00	0.64

*Includes transportation and import duties.

costs at foreign locations to be less than those in the United States. Canada, at 1.05, has the largest cost multiplier, largely because of high labor and material costs. Yugoslavia, on the other hand, has the lowest overall cost factor, 0.64, because of low labor and material (particularly structural steel) costs.

An examination of the total plant factors given in Table 12 indicates capital costs in some countries to be unusually low relative to similar costs in the United States. Costs in some of the European countries, e.g., Belgium, France, Spain, Sweden, United Kingdom and West Germany, where costs should be expected to approximate more closely United States costs, are especially noteworthy. One of the reasons for these "lower-than-expected" costs is the strength of the United States dollar in recent years. To illustrate, in 1979 the United States dollar was the equivalent of 0.69 European currency units (ECUs) while in 1983 the United States dollar was worth 1.21 ECUs. Even after adjustments for different rates of inflation in Europe and the United States--as is achieved via measuring "purchasing power parity"-the United States dollar has appreciated vis-a-vis most other European currencies. Similarly, the dollar has become stronger in other foreign markets as well. The final result of a strong United States dollar has been to reduce capital costs at most foreign locations relative to capital costs in the United States. To illustrate, capital costs in Norway in 1980 were estimated to be 100% of capital costs in the United States but in 1983 were estimated at only 88%. Additionally, capital costs in West Germany in 1980 were estimated at 96% of United States cost but only 82% of United States costs in 1983.

Table 13 provides total plant factors for 1980--the first full year in which the United States dollar began to appreciate vis-a-vis other currencies. It is included in this analysis partly to illustrate the impact of a strong United States dollar on capital costs in the 1980-1983 time period. When the dollar loses its strength, as most economists believe it will in time, the cost factors given in Table 13 (rather than those in Table 12) should serve as better indicators of relative capital costs.

Finally, the handbook user is again reminded that site-specific costs and factors should always be considered when making cost estimates. The relative cost data given here represent national averages (individual cities for some of the material CCFs), and intra-country cost variability can be substantial. This is particularly important when considering investments in remote areas of developing countries. These areas often lack essential infrastructure (roads, electric power, etc.) which can increase costs substantially. Mineral plants may also have to construct and maintain worker communities in remote sparsely-populated area. By some estimates these additional costs could add 25% or more to capital costs, particularly if electric power is not available.

TABLE 13. - Total plant cost factors - 1980

Country	Factor for onstruction labor U.S.=1.00	Factor for materials U.S.=1.00	Factor for equipment* U.S.=1.00	Factor for equipment usage U S =1.00	Factor for indirects U.S.=1.00	Factor for other costs U.S.=1.00	Total plant factor U.S.=1.00
Australia	0.63	1.00	1.07	1.00	0.67	1.00	0.91
Brazil	0.19	1.01	1.19	1.00	0.31	1.00	0.82
Canada	1.05	0.90	1.00	1.00	1.05	1.00	0.99
France	0.60	0.86	1.00	1.00	0.60	1.00	0.84
Ghana	0.23	0.94	-	1.00	0.58	1.00	-
Greece	0.52	1.02	1.14	1.00	0.65	1.00	0.91
Guinea	0.23	0.94	1.26	1.00	0.58	1.00	0.85
Guyana	0.27	1.15	1.29	1.00	0.55	1.00	0.91
India	0.23	0.96	1.21	1.00	0.29	1.00	0.82
Ireland	0.59	1.27	1.20	1.00	0.63	1.00	1.00
Italy	0.6	1.40	1.03	1.00	0.67	1.00	0.99
Jamaica	0.30	1.15	-	1.00	0.63	1.00	-
Japan	0.70	0.81	1.00	1.00	0.70	1.00	0.86
Norway	0.98	0.99	1.02	1.00	0.98	1.00	1.00
Spain	0.48	0.77	1.16	1.00	0.57	1.00	0.84
Surinam	0.39	1.15	1.23	1.00	0.64	1.00	0.93
Taiwan	0.40	1.22	1.02	1.00	0.50	1.00	0.88
Turkey	0.19	0.76	1.22	1.00	0.31	1.00	0.77
United Kingdom	0.67	1.25	1.00	1.00	0.67	1.00	0.96
United States	1.00	1.00	1.00	1.00	1.00	1.00	1.00
West Germany	0.80	1.10	1.00	1.00	0.80	1.00	0.96
Venzuela	0.39	0.71	-	1.00	0.54	1.00	-
Yugoslavia	0.29	0.59	1.09	1.00	0.35	1.00	0.72

*Includes transportation and import duties.

4. OPERATING COSTS CALCULATION

The cost curves and formulae presented for unit process area and general facility operating costs in Section 4.1 and 4.2 provide the cost data required to assemble the operating costs for a facility located in the United States. The steps required are similar to that for development of capital costs.

Table 14 is provided with this section to facilitate organization of costs and for reference to a particular costing section. The costs may be summed for total direct costs to which are added the indirect expenses of general facility costs.

Section 4.5 provides the procedure for adjusting the United States costs to other locations.

Section 4.1.5 provides operating costs for other technology and processes which may be substituted or added to the refining method used as a base for this costing system.

Unit processes used to produce alumina from bauxite are generally uniform throughout the industry. There are differences from plant to plant but these are minor compared to those in the non-ferrous metals industry in general. Operating costs are influenced more by costs for labor, fuel, caustic soda, etc., than by process differences. The only process difference of significance is related to the mineralogical characteristics of the bauxite feed. Traditionally, American plants have treated bauxites that contain the alumina trihydrate gibbsite as the main constituent. Gibbsite leaches relatively rapidly at moderate temperatures (typically about 130 degrees Celsius) and pressures. European bauxites contain mostly monohydrate boehmite and/or diaspore requiring much higher temperatures (typically 230 degrees Celsius) and pressures.

In recent years the trend has been toward the high temperature process which allows treatment of mixed ores rather than being dependent on increasingly scarce trihydrate bauxite as feed material. The monohydrate process is more expensive to operate than the trihydrate process. The difference is in energy consumption (both steam and electric power), caustic soda consumption (more silica is dissolved at higher temperatures) and in maintenance (high-pressure pumps, seals, more equipment). As far as operating costs are concerned, virtually the only area affected is the digestion area with its associated heat-up and cool-down sections. In the following sections separate estimates are provided for monohydrate and trihydrate processing.

4.1. REFINING UNIT PROCESS COSTS

Included in this section are the information, equations and graphic representations that allow the user to calculate operating costs for unit processes.

TABLE 14
OPERATING COST SUMMARY
ALUMINA REFINERY FACILITY

DATA
Location _____

Capacity:
Alumina (mtpy) _____
Bauxite (mtpy) % ALUMINA ____ _____
Recovery % ALUMINA ____ _____

Country Cost Factors _____ _____ _____ _____

Unit Process Description	Section	Labor	Supplies	Energy	Total
REFINING					
BAUXITE SLURRY PREP/DIGEST	4.1.1				
High Temperature	4.1.1.1				
Low Temperature	4.1.1.2				
CLARIFICATION/FILTRATION	4.1.2				
HEAT EXCHANGE/PRECIPITATE and CLASSIFICATION	4.1.3				
CALCINATION/ALUMINA STG.	4.1.4				
Subtotal					
GENERAL/ADMINISTRATIVE					
GENERAL PLANT	4.2.1				
POWER SUPPLY SYSTEM	4.2.2				
MATERIAL HANDLING	4.2.3				
ADMINISTRATIVE SERVICES	4.2.4				
Supervision					
Subtotal					
ENVIRONMENTAL	4.3				
TOTAL OPERATING COSTS					

4.1.1. BAUXITE SLURRY PREPARATION AND DIGESTION - MONOHYDRATE PROCESS

This area includes bauxite receiving, storage and reclaim, grinding and classification, and digestion with its liquor heating and slurry cooling system. The digestion temperature is assumed to be 230 degrees Celsius. Operating and maintenance labor manning requirements for those different plant sizes are as follows:

	Metric Tons Alumina Produced Year		
Manpower	600,000	1,000,000	2,000,000
Operating Labor	46	52	62
Maintenance Labor	72	105	177

The supplies costs are divided as follows:

Maintenance Supplies	16%
Industrial Chemicals	83%
Miscellaneous	1%

The energy costs are divided into the following type of energy:

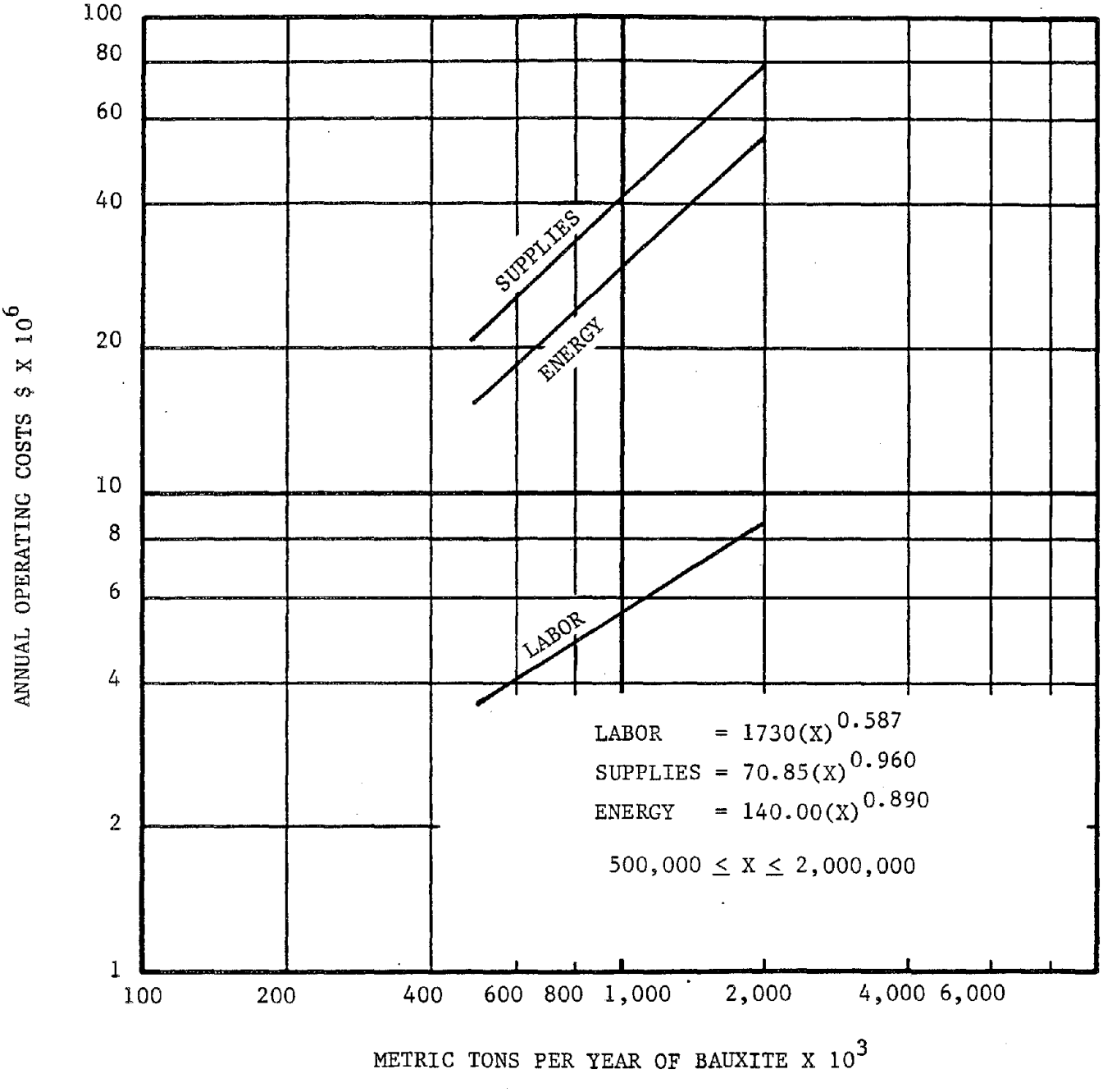
Steam	79%
Electric Power	21%

The regression equations for the annual costs are:

Labor: Annual Cost = $1,730(X)^{0.587}$

Supplies: Annual Cost = $70.85(X)^{0.960}$

Energy: Annual Cost = $140.0(X)^{0.890}$



4.1.1. BAUXITE SLURRY PREPARATION AND DIGESTION - HIGH TEMPERATURE DIGESTION

SCALE—LOGARITHMIC

4.1.1.1. TRIHYDRATE PROCESS

The operating temperature for the trihydrate process is assumed to be 130 degrees Celsius. Because of lower temperatures and pressures, maintenance costs as well as supplies and energy costs are lower than for the monohydrate process. Total direct operating costs are about 30% lower than for the same area in the monohydrate plant. Manning levels are as follows:

	Metric Tons Alumina Produced Per Year		
Manpower	600,000	1,000,000	2,000,000
Operating Labor	42	48	57
Maintenance Labor	53	76	123

The supplies costs are divided as follows:

Maintenance Supplies	18%
Industrial Chemicals	80%
Miscellaneous	2%

The energy costs are divided into the following types of energy:

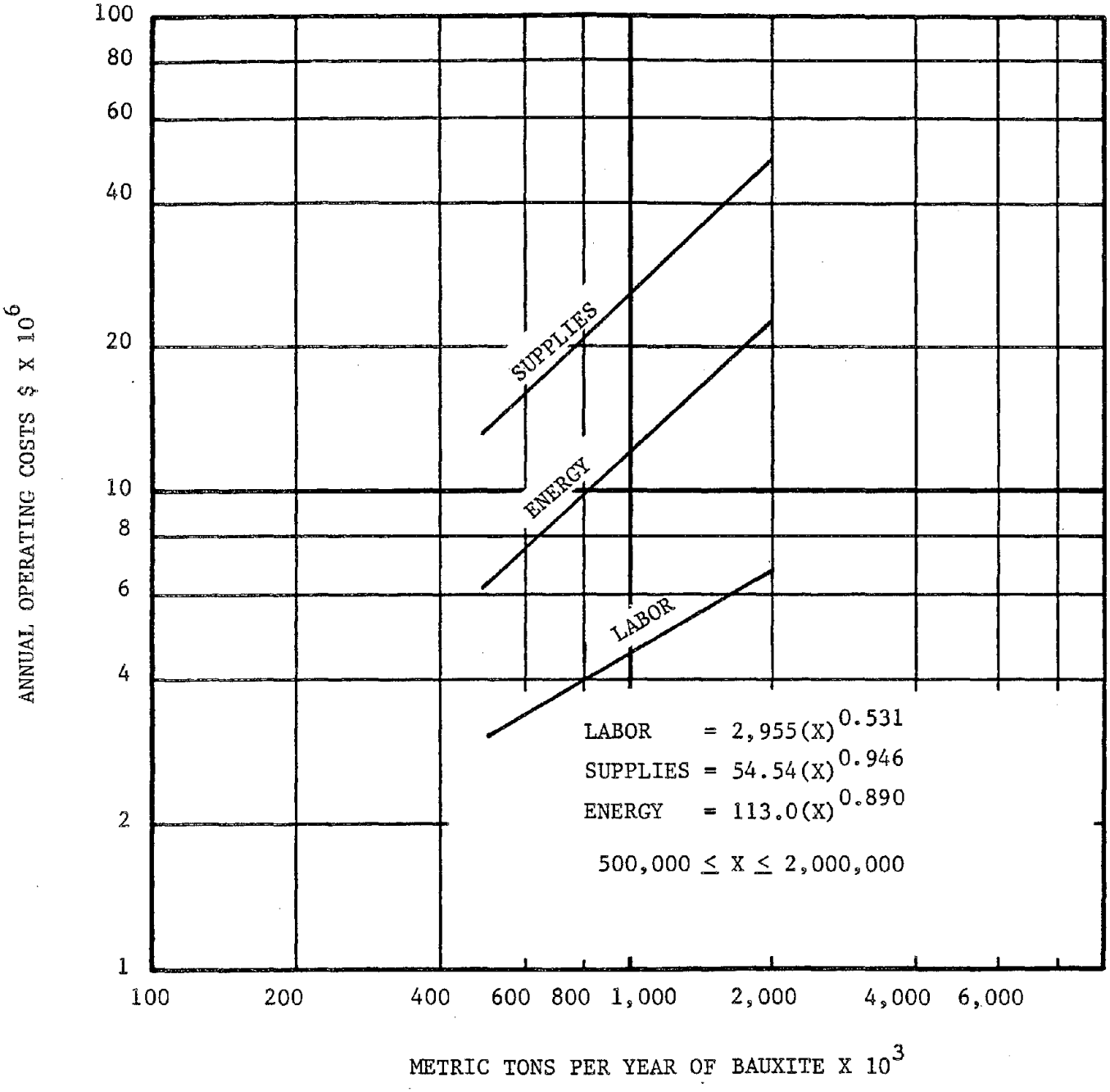
Steam	83%
Electric Power	17%

The regression equation for annual operating costs are:

Labor: Annual Cost = $2,955(X)^{0.531}$

Supplies: Annual Cost = $54.54(X)^{0.946}$

Energy: Annual Cost = $113.0(X)^{0.890}$



4.1.1.1. BAUXITE SLURRY PREPARATION AND DIGESTION - LOW TEMPERATURE DIGESTION

SCALE—LOGARITHMIC

4.1.2. CLARIFICATION AND MUD WASHING, FILTRATION

This area includes clarification and mud washing, lime slaking, red mud filtration and disposal, filter aids and acid handling. Manning levels are as follows:

	Metric Tons Alumina Produced Per Year		
Manpower	600,000	1,000,000	2,000,000
Operating Labor	32	36	43
Maintenance Labor	23	34	57

The supplies costs are divided as follows:

Maintenance Supplies	32%
Industrial Chemicals	68%

The energy costs are divided into the following type of energy:

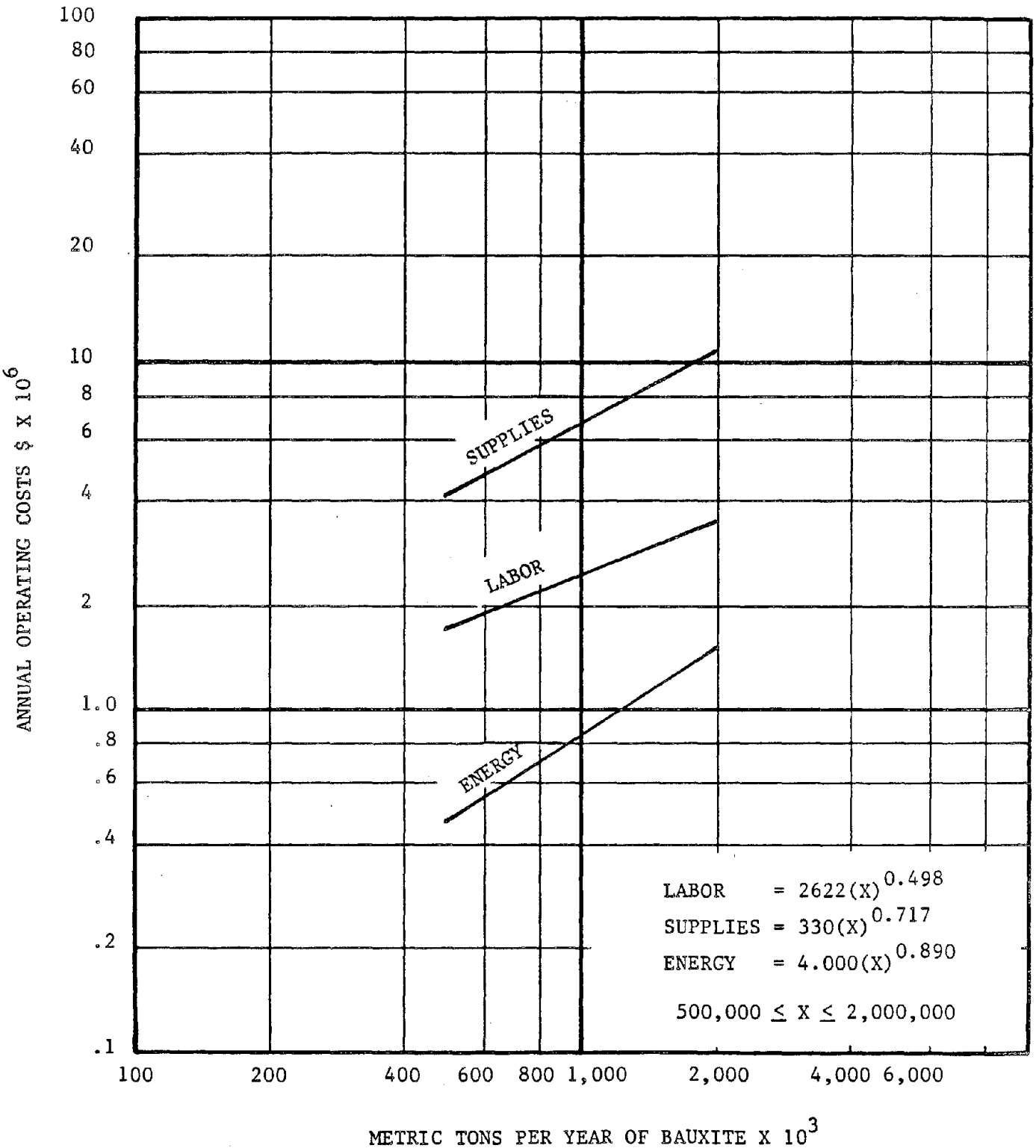
Electric Power	100%

The regression equations for annual operating cost components as follows:

Labor: Annual Cost = $2,662(X)^{0.498}$

Supplies: Annual Cost = $330.0(X)^{0.717}$

Energy: Annual Cost = $4.000(X)^{0.890}$



4.1.2. CLARIFICATION AND MUD WASHING, FILTRATION

SCALE–LOGARITHMIC

4.1.3. HEAT EXCHANGE, PRECIPITATION AND HYDRATE CLASSIFICATION

This area includes heat exchange, hydrate precipitation and classification and evaporation. Manning levels are as follows:

	Metric Tons Alumina Produced Per Year		
Manpower	600,000	1,000,000	2,000,000
Operating Labor	32	36	43
Maintenance Labor	33	48	81

The supplies costs are divided as follows;

Maintenance Supplies	71%
Miscellaneous	29%

The energy costs are divided into the following types of energy:

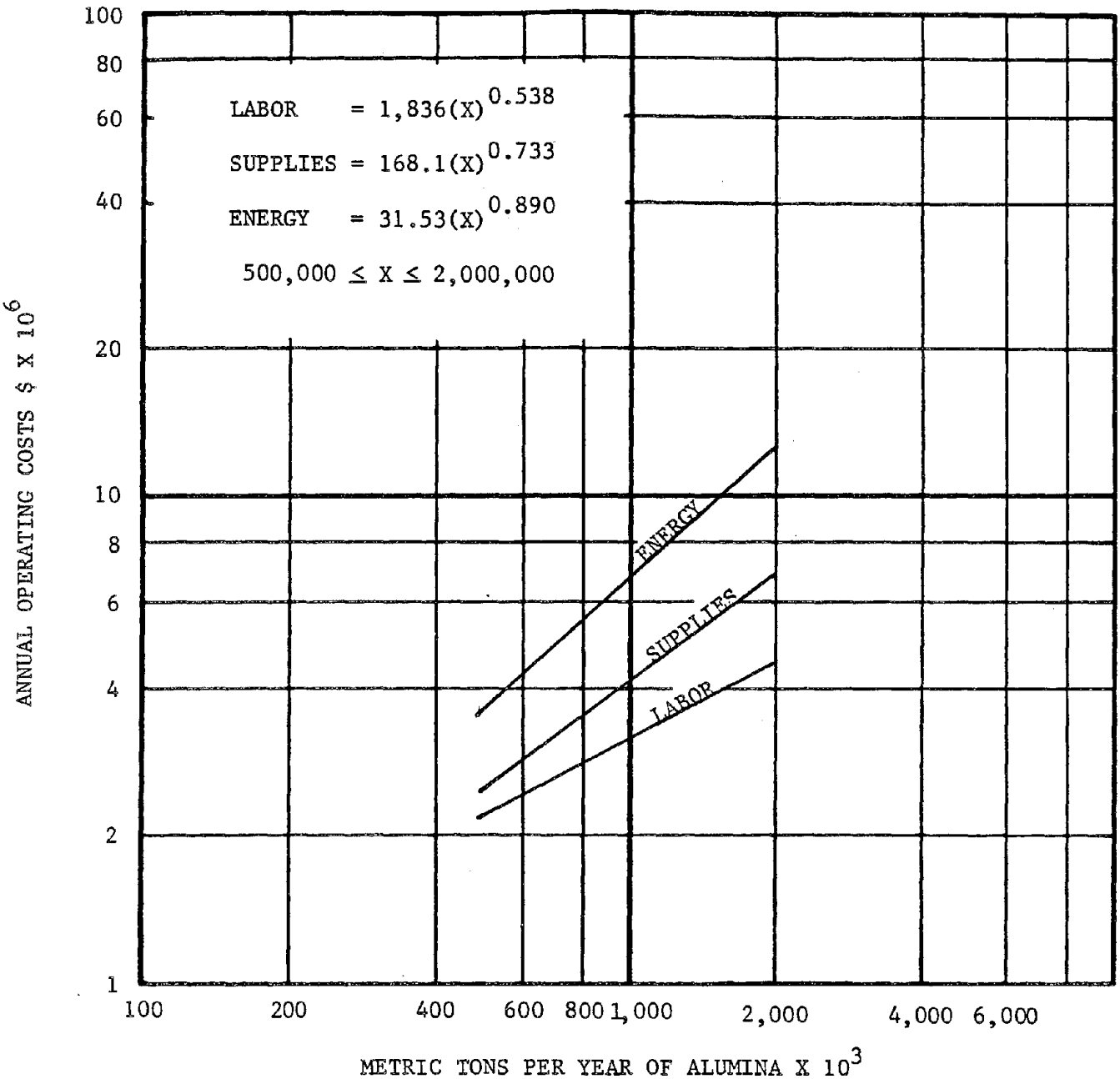
Steam	64%
Electric Power	36%

The regression equations for annual operating cost components are as follows:

Labor: Annual Cost = $1,836(X)^{0.538}$

Supplies Annual Cost = $168.1(X)^{0.733}$

Energy: Annual Cost = $31.53(X)^{0.890}$



4.1.3. HEAT EXCHANGE, PRECIPITATION AND HYDRATE CLASSIFICATION

SCALE–LOGARITHMIC

4.1.4. CALCINATION AND ALUMINA STORAGE

This area includes hydrate filtration, calcination and alumina storage and reclaim. The manning levels are as follows:

	Metric Tons Alumina Produced Per Year		
Manpower	600,000	1,000,000	2,000,000
Operating Labor	32	36	43
Maintenance Labor	52	76	128

The supplies costs are divided as follows:

Maintenance Supplies	92%
Miscellaneous	8%

The energy costs are divided into the following types of energy:

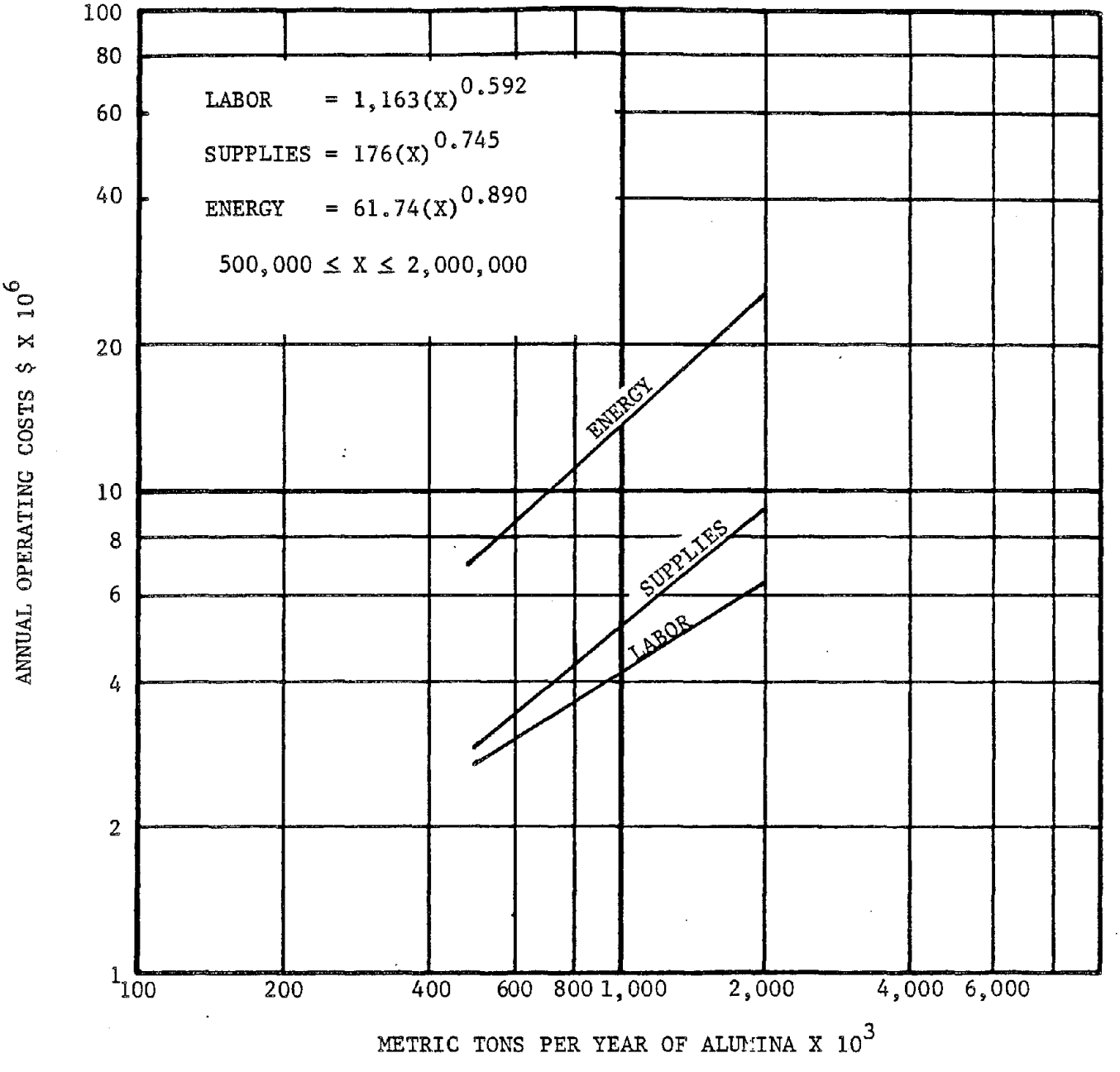
Fuel Oil	94%
Electric Power	6%

The regression equations for the components of annual operating costs are:

Labor: Annual Cost = $1,163(X)^{0.592}$

Supplies: Annual Cost = $176.0(X)^{0.745}$

Energy: Annual Cost = $61.74((X)^{0.890}$



4.1.4. CALCINATION AND ALUMINA STORAGE

SCALE–LOGARITHMIC

4.2. GENERAL FACILITY COSTS

The General Facilities include General Plant, Power and Steam Supply, Port Facilities and Administration Services. All costs tabulated for these areas should be added to the direct costs obtained for the plant operating costs with the exception of the costs for Power and Steam supply. These costs have already been allocated to the operating areas.

All operating and maintenance supervisors are included with the administrative personnel under Administration Services.

4.2.1. GENERAL PLANT

This area includes yard maintenance, primary water, fuel oil and diesel fuel distribution, service buildings and sanitation system. The manning levels are as follows:

	Metric Tons Alumina Produced Per Year		
Manpower	600,000	1,000,000	2,000,000
Operating Labor	46	52	62
Maintenance Labor	7	10	17

The supplies costs are divided as follows:

Maintenance Supplies	81%
Miscellaneous	19%

The energy costs are divided into the following types of energy:

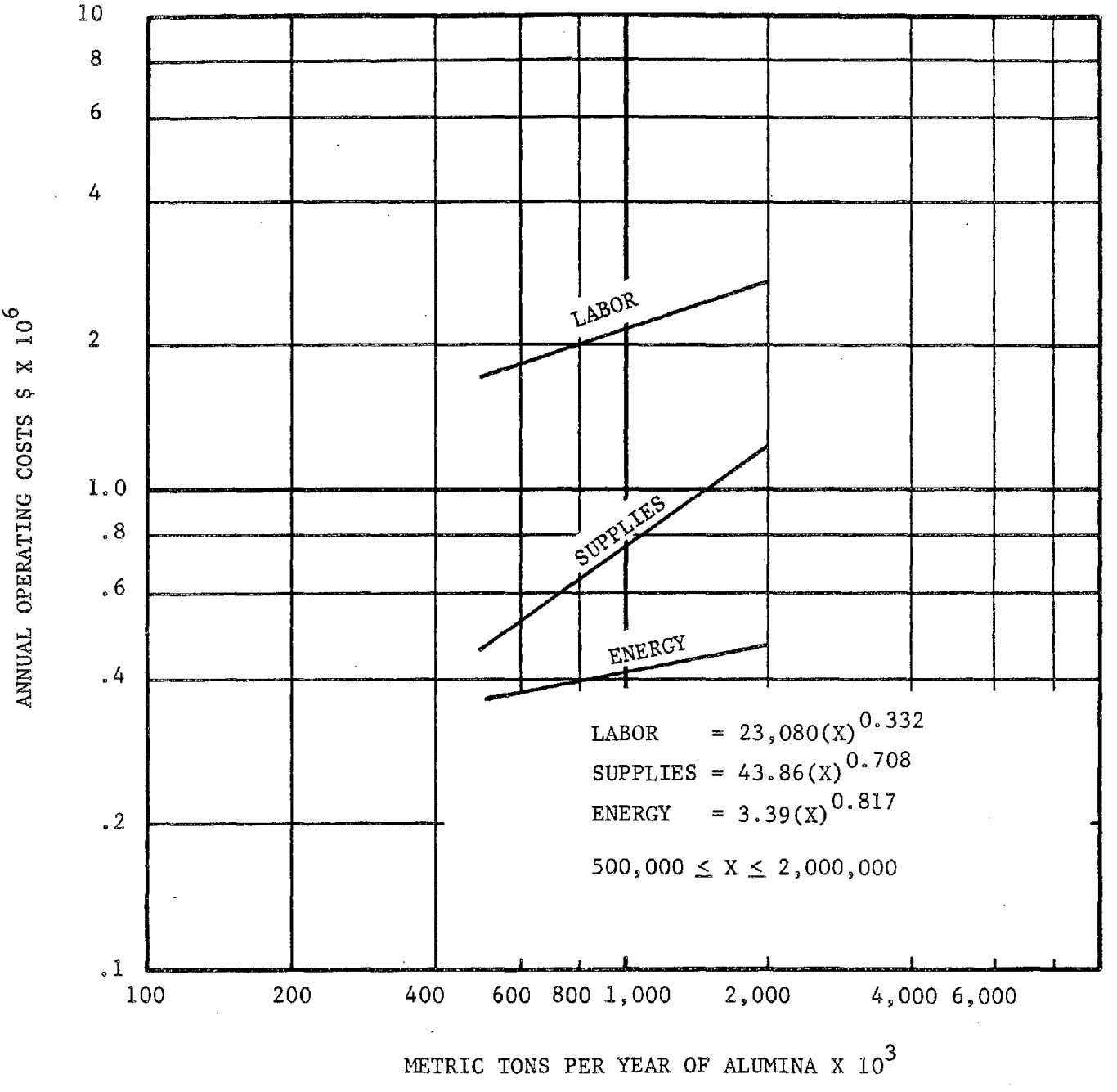
Fuel Oil	1%
Electric Power	99%

The regression equations for annual costs are:

Labor: Annual Cost = $23,080(X)^{0.332}$

Supplies: Annual Cost = $43.86(X)^{0.708}$

Energy: Annual Cost = $3.39(X)^{0.817}$



4.2.1. GENERAL PLANT

SCALE—LOGARITHMIC

4.2.2. POWER SUPPLY SYSTEM

A boiler fired with No. 6 Fuel Oil is assumed to produce high pressure steam that runs back-pressure turbines. The turbines run generators producing 40 MW power for the intermediate size plant and the turbine exhaust steam is utilized for the process. Manning levels are as follows:

	Metric Tons Alumina Produced Per Year		
Manpower	600,000	1,000,000	2,000,000
Operating Labor	18	21	25
Maintenance Labor	14	21	35

The supplies costs are divided as follows:

Maintenance Supplies	84%
Miscellaneous	16%

The energy costs are divided into the following types of energy:

Fuel Oil	99%
Electric Power	1%

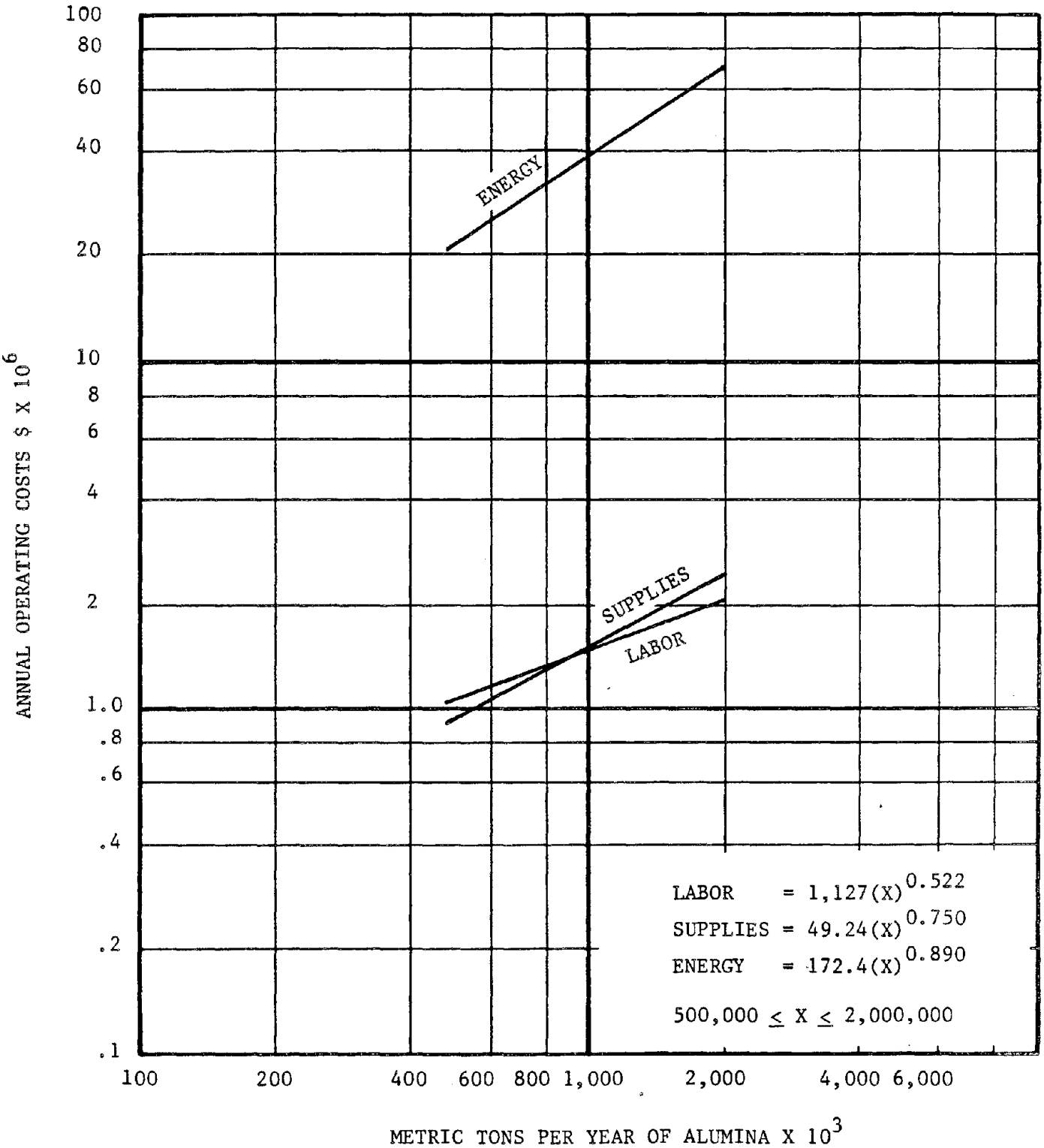
The regression equations for annual costs are:

Labor: Annual Cost = $1,127(X)^{0.522}$

Supplies: Annual Cost = $49.24(X)^{0.750}$

Energy: Annual Cost = $172.9(X)^{0.890}$

Please note that these costs should not be added to the operating costs. They have already been accounted for by the price of steam and electricity used in the operation.



4.2.2. POWER SUPPLY SYSTEM

SCALE–LOGARITHMIC

4.2.3. MATERIALS HANDLING

The Port Facilities are designed to handle incoming raw materials such as bauxite, fuel and caustic soda, as well as alumina product. Manning levels are as follows:

	Metric Tons Alumina Produced Per Year		
Manpower	600,000	1,000,000	2,000,000
Operating Labor	14	16	19
Maintenance Labor	12	16	23

The supplies costs are divided as follows:

Maintenance Supplies	99%
Miscellaneous	1%

The energy costs are divided into the following types of energy:

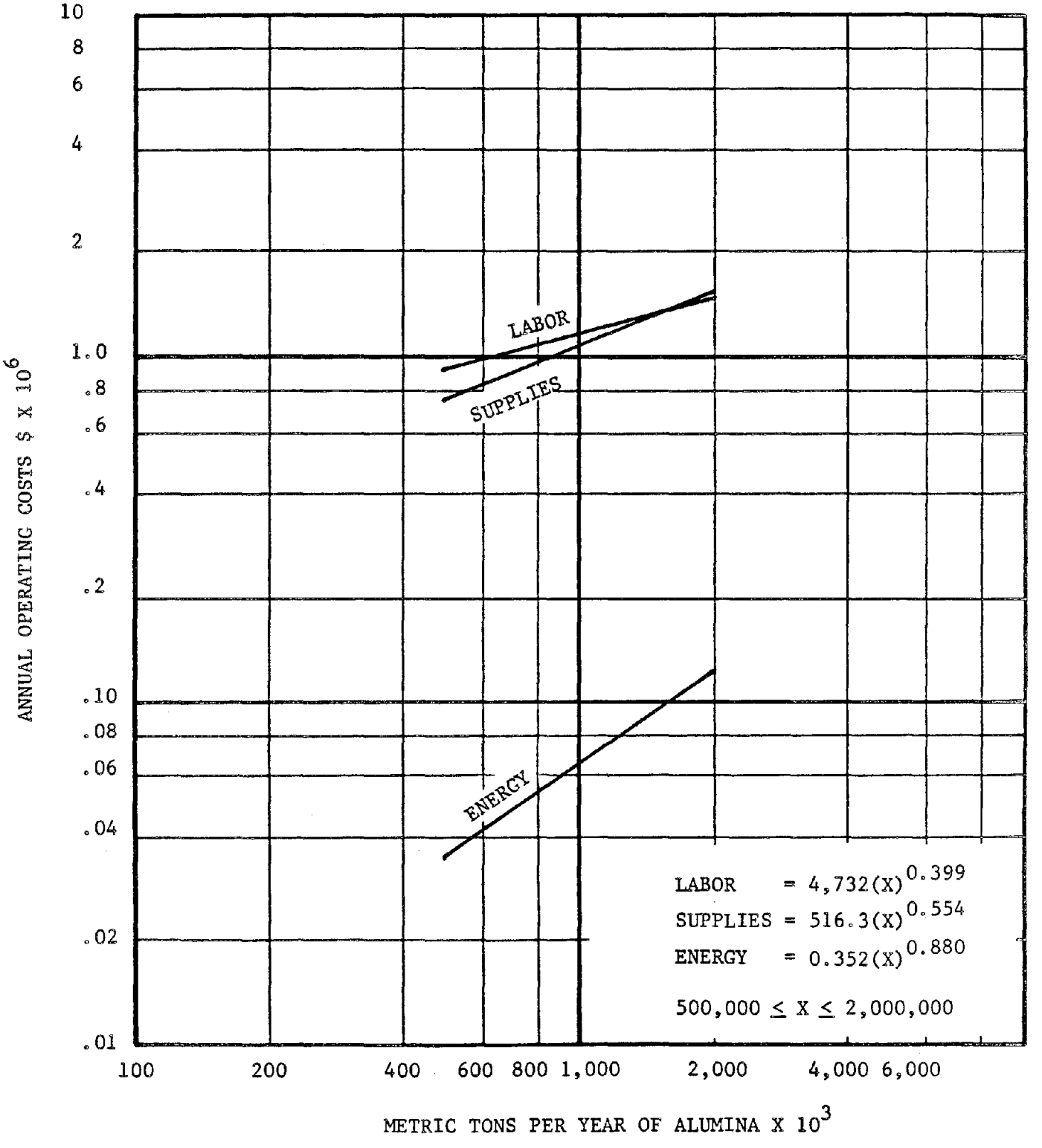
Fuel Oil	13%
Electric Power	87%

The regression equations for the annual costs are:

Labor: Annual Cost = $4,732(X)^{0.399}$

Supplies: Annual Cost = $516.3(X)^{0.554}$

Energy: Annual Cost = $0.352(X)^{0.880}$



4.2.3. MATERIAL HANDLING

SCALE–LOGARITHMIC

4.2.4. ADMINISTRATIVE SERVICES

This section includes all office expenses. Included under supplies are items such as insurance, property taxes, telephone costs and rental, and maintenance of office equipment. A fourth category of costs has been added under the heading of Plant Supervision. This includes all plant operating and maintenance supervision with the exception of the supervision in the power plant because these costs have been incorporated in the electricity and steam charges. Manning levels are as follows:

	Metric Tons Alumina Produced Per Year		
Manpower	600,000	1,000,000	2,000,000
Office	61	68	78
Maintenance Labor	2	2	3
Plant Operating Supervision	35	41	49
Plant Maintenance Supervision	44	63	104

The supplies costs are divided as follows:

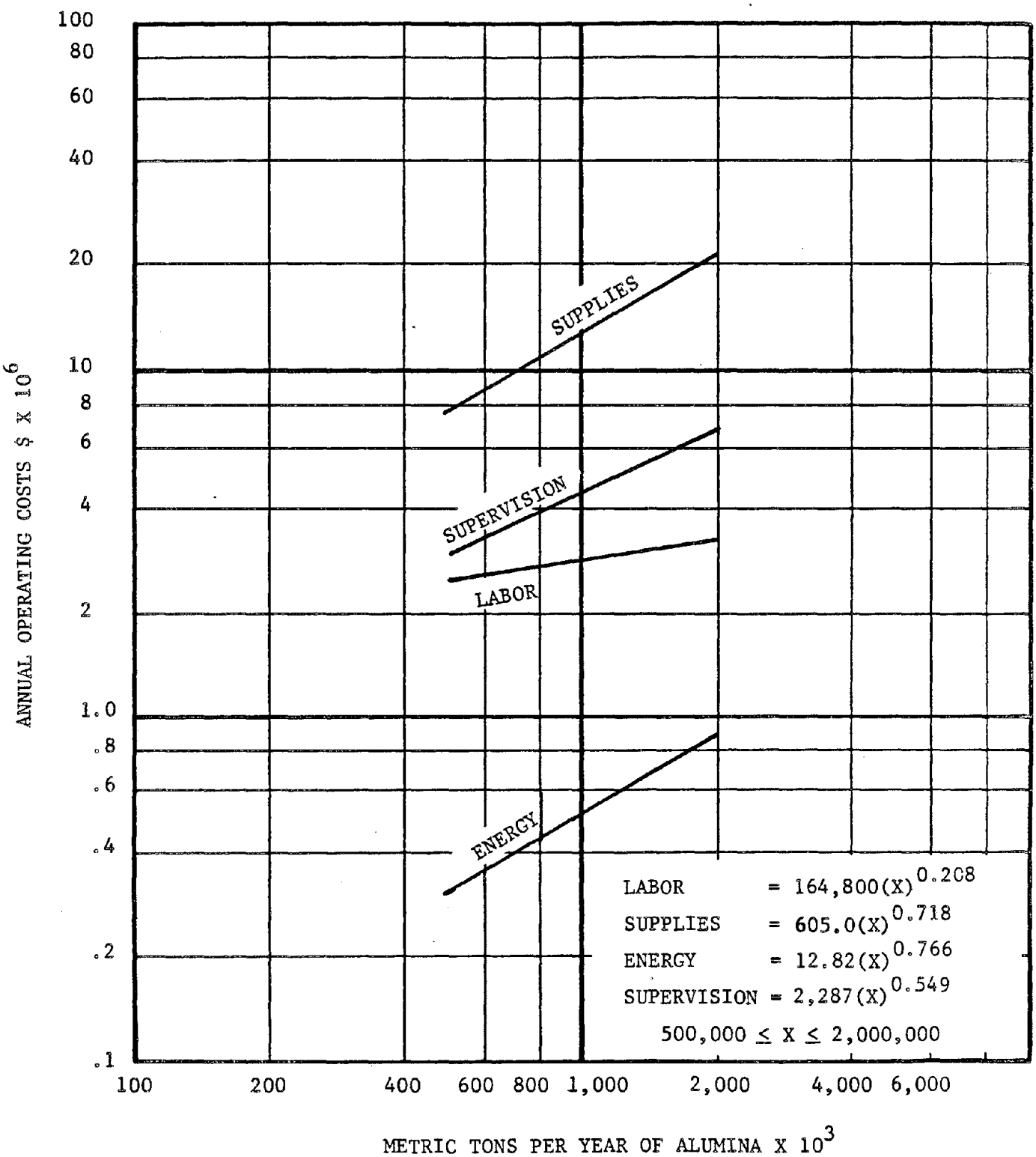
Maintenance	1%
Taxes, Insurance and Misc.	99%

The energy costs are divided into the following types of energy:

Fuel Oil	66%
Electric Power	34%

The regression equations for the various cost components are:

Office and Maintenance Labor:	$\text{Annual Cost} = 164{,}800(X)^{0.208}$
Supplies:	$\text{Annual Cost} = 605.0(X)^{0.718}$
Energy:	$\text{Annual Cost} = 12.82(X)^{0.766}$
Plant Supervision:	$\text{Annual Cost} = 2{,}287(X)^{0.549}$



4.2.4. ADMINISTRATIVE SERVICES

SCALE--LOGARITHMIC

4.3. ENVIRONMENTAL CONTROL SYSTEMS OPERATING COSTS

The environmental control systems that are required for an alumina refinery are associated mainly with direct control at material handling transfer points. Fabric filler dust collectors sized for the 1,000,000 mtpy facility and described in Section 3.3 are sized as follows:

TABLE 15

REFINING

ENVIRONMENTAL CONTROL SYSTEMS

Area	Number Required	Flow	Power Required
Bauxite Slurry Preparation	6	8,400 m^3/hr	7.5 KW ea
	7	4,700 m^3/hr	5.5 KW ea
	3	16,500 m^3/hr	15 KW ea
Alumina Handling and Storage	2	46,000 m^3/hr	75 KW ea
	4	6,000 m^3/hr	7 KW ea
	2	5,700 m^3/hr	3 KW ea
	2	3,000 m^3/hr	5.5 KW ea
	1	1,700 m^3/hr	1.5 KW ea
Starch Facility	2	1,700 m^3/hr	1.6 KW ea

The supplies costs are divided as follows:

Maintenance	71%
Filter Bags, etc.	29%

The energy costs are divided into the following types of energy:

Electric Power	100%

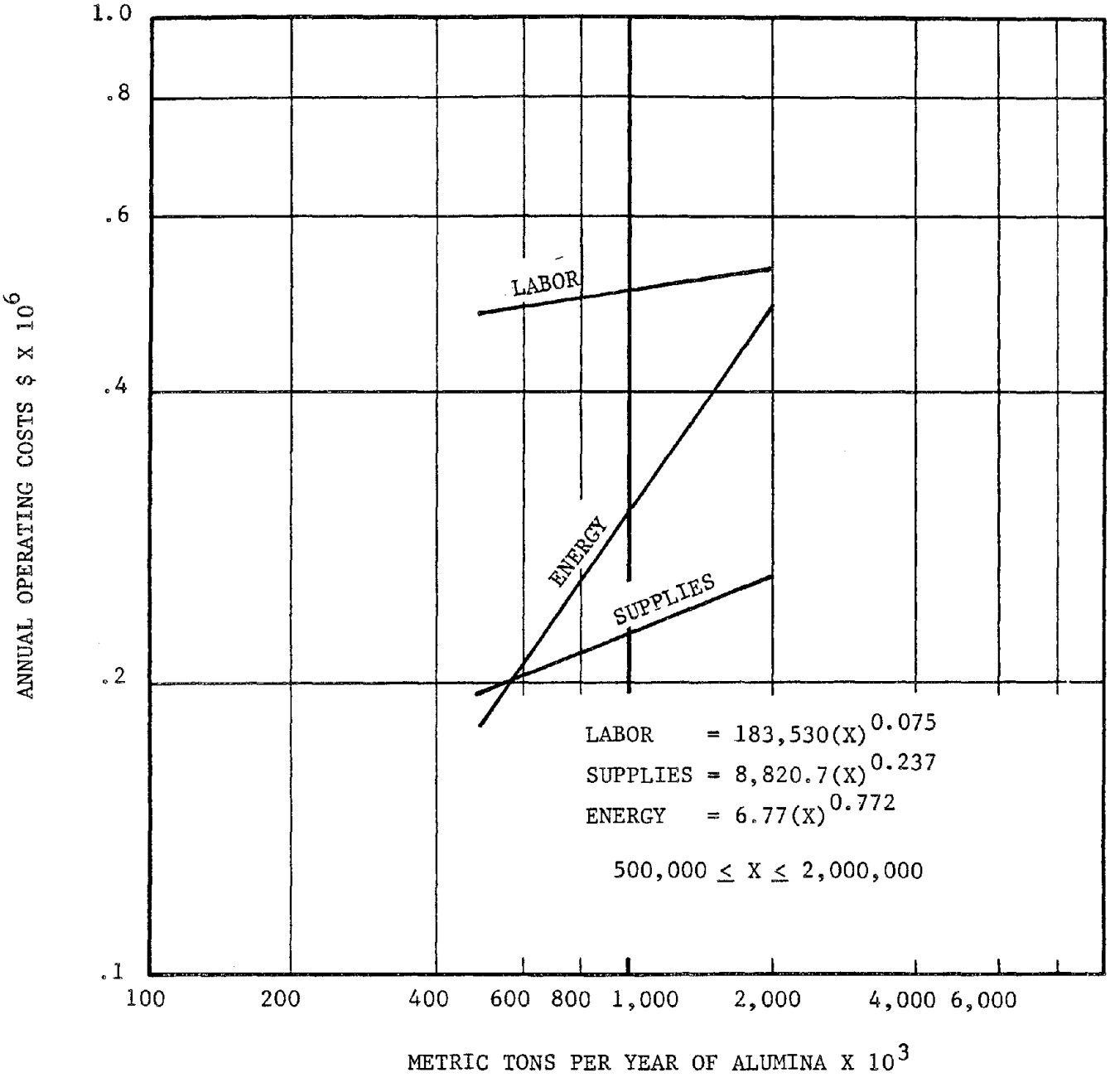
The regression equations for the operating costs of the above units are:

Labor: Annual Cost = $183,530(X)^{0.075}$

Supplies: Annual Cost = $8,820.7(X)^{0.237}$

Energy Annual Cost = $6.77(X)^{0.772}$

In addition to the refining area environmental control systems, the general facilities include environmental systems consisting of electrostatic precipitators for collecting ash from the power plant boiler offgas.



4.3. ENVIRONMENTAL CONTROL SYSTEMS OPERATING COSTS

SCALE–LOGARITHMIC

4.4. FIXED AND VARIABLE COSTS

Associated with each unit process area are costs that are influenced by reduced rates of production from the design capacity rate. Certain costs vary directly with the production rate while others vary slightly. This section attempts to fix this variation by unit process so that adjustments can be made to the operating costs developed in Section 4. The following table provides the means for cost adjustment to each unit process for changes in production. The turndown is by a reduction in plant continuing throughput when possible.

All process units are reduced in capacity by turndown rather than a reduction in shift operation. A reduction in shift operations or periodic curtailment may achieve a reduction in operating labor but an increase in maintenance labor and supplies. As a result of this operating philosophy, most of the general plant facilities are also reduced in capacity by means of turndown. Exceptions are the materials handling area where costs are directly related to the quantity of materials handled. The administration and services costs are constant regardless of capacity.

TABLE 16

OPERATING COST ADJUSTMENTS

SECTION	UNIT PROCESS	LABOR	SUPPLIES			ENERGY		
			Maintenance	Industrial Chemicals	Misc.	Fuel Oil	Steam	Power
4.1.1	Bauxite Slurry Preparation	X/Y	1.0	X/Y	X/Y	-	X/Y	X/Y
4.1.2	Classification and Mud Washing	1.0	1.0	X/Y	X/Y	-	-	X/Y
4.1.3	Heat Interchange	1.0	1.0	-	X/Y	-	X/Y	X/Y
4.1.4	Calcination	1.0	1.0	-	X/Y	X/Y	-	X/Y
4.2.1	General Plant	1.0	1.0	-	X/Y	X/Y	-	X/Y
4.2.2	Power Supply	1.0	1.0	-	X/Y	X/Y	-	X/Y
4.2.3	Materials Handling	X/Y	X/Y	-	X/Y	X/Y	-	X/Y
4.2.4	Administrative	1.0	1.0	-	1.0	1.0	-	1.0
4.3	Environmental	1.0	1.0	-	1.0	-	-	1.0

NOTES: Adjust costs calculated in Sections 4.1, 4.2 and 4.3 by ratio of reduced capacity throughput (X) divided by design capacity (Y) or as noted.

4.5. TRANSLATION OF OPERATING COST METHODOLOGY

The basic method used for estimating operating costs for post-mill processing facilities in foreign locations, given cost estimates for an equivalent United States facility, parallels exactly the procedures discussed in Section 3.5 for capital cost translation using cost conversion factors (CCFs). The CCF is defined as the ratio of the cost (expressed in $US) in the country of interest to that in the United States. Thus, for example, if the CFF were numerically equal to 1.2 and the estimated United States costs were $80 million the estimated cost (in $US) of the foreign facility would be 1.2(00) or $96 million.

As was done for capital costs, operating costs are subdivided into several cost categories and separate CCFs are provided for costs in each of these categories. For the purpose of this study, the following major component cost categories have been designated: (1) alumina refining costs, (2) general facility costs and (3) environmental control systems costs. CCFs for these categories are calculated as the ratio of the estimated cost in the host country (converted to United States dollar terms) to that in the United States. Since foreign location costs are being compared to costs in the United States, cost factors for the latter are unity by definition.

Elements of the major cost categories and their respective percentage of the costs of a typical United States facility are:

(a) Alumina refining costs (84% of total) - included are costs of hourly operating and maintenance labor (herein referred to as simply operating labor), i.e., including wages and burden; energy and supplies incurred in direct process operations (e.g., bauxite storage, grinding, digestion, desilication, caustic handling, clarification, precipitation and calcination). Each component of refining costs is further discussed below.

- o Operating labor - factors compare wage rates in foreign countries with those in the United States. CCFs also reflect differing levels of labor productivity.

- o Energy - included are costs of No. 6 and No. 2 fuel oil with the former accounting for more than 99% of the energy cost.

  Note: Electric power costs are not listed as a separate energy cost item because the electric power utilized is self-generated at the plant by either burning No. 6 (heavy) fuel oil or coal. However, insofar as the United States base-case plant it is assumed to burn fuel oil only (costs are excluded from the derivation of energy cost factors).

- o Supplies - operating supplies for alumina refining generally consist of caustic soda, flocculants, lime, hydrochloric acid and sulfuric acid.

(b) General facility costs (16% of total) - included are the costs of hourly operating (and maintenance) labor, plus salaried supervisory labor; energy and supplies incurred in the operation and maintenance of general support facilities, e.g., warehouses, laboratories, maintenance shops, change houses and lunchrooms, etc. Also included are general and administrative costs.

(c) Environmental control systems costs (-% of total) - included here are the costs of operating labor, energy and supplies incurred in the operation and maintenance of environmental control equipment.

The methodology described below enables the handbook user to translate estimated United States costs to foreign locations. Numerical cost factors are provided in the following sections of methodology discussion.

4.5.1. TRANSLATION OF REFINING COSTS

Alumina refining costs comprise three component cost elements: direct operating labor, energy and supplies. The methodology and appropriate cost factors for translating each to foreign locations are provided below.

4.5.1.1. TRANSLATION OF DIRECT OPERATING LABOR COSTS

Direct labor costs for the United States base-case facility include wages paid to workers and burden figured at 56.8% of the basic wage rate. In common with the construction labor cost analysis, burden in foreign countries is assumed to be approximately equivalent (in percentage terms) to that in the United States. Because of the assumption, differences in labor costs between foreign countries and the United States are the result of differing levels of wage rates and productivity. Analysis indicates that countries with lower wage rates also have lower productivity than their industrialized counterparts. Thus, these countries do not enjoy quite the labor cost advantage that their low wages would indicate. Consider Venezuela as an example. Based on 1983 estimates, a Venezuelan laborer employed in the basic nonferrous metals processing industry earned a straight wage of approximately $3.33 per hour (or $5.22 per hour after burden adjustment). The corresponding United States worker earned a basis wage of $9.51 per hour ($14.91 after burden adjustments). Venezuela's operating wage rate was only 35.0% of the same rate in the United States. However, when productivity differences are taken into account, the relative labor costs in Venezuela increase to 50% of those in the United States. This is because an alumina refining facility plant operated in Venezuela would employ more laborers

than would a corresponding facility in the United States. Analysis of data on worldwide alumina plant manning levels lead to the following equation for prediction of the number of employees:

$$Y_i = 406.26\ CAP^{0.495}\ \ GNPCAP^{-0.296} \quad (1)$$

where

Y_i = predicted number of employees at facility "i"

CAP_i = annual plant capacity (000 metric tons) of facility "i", and

$GNPCAP_i$ = the Gross National Product per capita ($US) of the host country where facility "i" is located.

For example, using the above equation to predict the employment at Venezuela's Interalumina facility (CAP = 1,000 GNPCAP = $4,140) results in an estimate of the work force of 1,055 employees, which is within 20% of the actual reported work force of 1,306 employees. Statistical analysis indicates that approximately 68% of the predicted employment levels are within a factor of from 0.72 to 1.38 of the reported employment.

If this same facility were to be located in the United States, an estimated 734 workers would be employed, lower by a factor of 1.44, the relative productivity factor shown in column 7 of Table 17. Thus, the effective labor cost is the relative wage rate, 0.35 (column 4 of Table 17), multiplied by the relative manpower required, 1.44 (column 7 of Table 17) or .50, the CCF given above and shown in column 8 of Table 17.

Table 17 provides the requisite CCFs needed to translate operating labor costs to locations abroad. Column 1 of this table lists all of the market economy countries that house (as of this writing) an alumina processing facility. Column 2 provides an estimated wage for refinery type workers in these countries. Column 3 provides labor cost data adjusted for burden. The adjustment for each case is 1.568, indicating burden to be 56.8% of the direct wage. Uniform adjustments for burden are made necessary by the lack of reliable country-specific information for all countries of interest. Based upon data from a sample of the countries, it is concluded that the error associated with this assumption is less than 25%. Column 4 shows the ratio of "loaded" wages in the host country to those in the United States.

TABLE 17. - Wage rates, productivity factors and operating labor conversion factors - 1983

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Country	1983 Wage rate[1] $U.S./h	1983 Wages adjusted for burden[2] $U.S./h	Ratio of 1983 wages and burden U.S.=1.00	1983 GNP per capita $U.S.	Ratio of GNP per capita U.S.=1.00	Productivity factor[3] U.S.=1.00	Conversion factor U.S.=1.00
Australia	7.57	11.87	0.80	10,780	0.77	1.08	0.86
Brazil	1.72	2.70	0.18	1,890	0.13	1.83	0.33
Canada	8.30	13.01	0.87	12,000	0.85	1.05	0.91
France	7.34	11.51	0.77	10,390	0.74	1.09	0.84
Ghana	0.38	0.60	0.04	320	0.02	3.18	0.13
Greece	3.24	5.08	0.34	3,970	0.28	1.46	0.50
Guinea	0.36	0.56	0.04	300	0.02	3.18	0.13
Guyana	0.57	0.89	0.06	520	0.04	2.59	0.16
India	0.32	0.50	0.03	260	0.02	3.18	0.10
Ireland	3.81	5.97	0.40	4,810	0.34	1.38	0.55
Italy	4.83	7.57	0.51	6,350	0.45	1.27	0.65
Jamica	1.25	1.96	0.13	1,300	0.09	2.04	0.27
Japan	7.17	11.24	0.75	10,100	0.72	1.10	0.83
Norway	9.36	14.68	0.99	13,820	0.98	1.01	1.00
Spain	3.80	5.96	0.40	4,800	0.34	1.38	0.55
Suriname	2.92	4.58	0.31	3,520	0.25	1.51	0.47
Taiwan	2.31	3.62	0.24	2,670	0.20	1.61	0.39
Turkey	1.19	1.87	0.13	1,230	0.09	2.04	0.27
United Kingdom	6.53	10.24	0.69	9,050	0.64	1.14	0.79
United States	**9.51**	**14.91**	**1.00**	**14,090**	**1.00**	**1.00**	**1.00**
West Germany	7.96	12.48	0.84	11,420	0.81	1.06	0.89
Venezuela	3.33	5.22	0.35	4,100	0.29	1.44	0.50
Yugoslavia	2.23	3.50	0.23	2,570	0.18	1.66	0.38

[1]Estimated from 1983 GNP per capita. For a detailed discussion of estimating wages from GNP per capita see the working paper titled, "Estimating Operating and Construction Wage Rates," December 13, 1984.

[2]Fringe of 56.8% assumed for workers in all countries.

[3]Estimated from 1983 GNP per capita using a methodology similar to that developed in the working paper titled, "Direct Productivity Estimation for Lead Smelting and Refining Operations - Superior to Value-Added Approaches," December 12, 1984.

Columns 5 and 6 of the table provide Gross National Product (GNP) per capita data and the ratio of GNP per capita between the host country and the United States, respectively. The latter is important because it is used to calculate the foreign productivity factors appearing in column 7. Column 8 contains the resulting labor CCFs (i.e., the product of columns 4 and 7). These conversion factors vary from a minimum of 0.10 in India--indicating operating labor costs in these two countries to be 10% of that in the United States--and to a maximum of 1.00 in Norway where labor costs equal those in the United States.

For translating operating labor costs--by far the largest component cost category for United States plants--to foreign locations, the user of the handbook is directed to column 8. Multiplication of the operating labor cost associated with a particular process at the United States base-case plant--which is obtained from various cost curves presented in Section 4.0 of the handbook--by the appropriate CCF listed in column 8 results in an estimated cost of operating labor in the country of interest. For example, if the operating labor cost for a particular unit process at the United States base-case plant is $5 million, then the same cost is on $2.5 million in Venezuela (i.e., 5 x 0.5 = 2.5).

Operating labor costs for other processes and other countries are calculated using other process cost curves and other country operating labor cost factors, respectively, before being summed to a total.

4.5.1.2. TRANSLATION OF DIRECT OPERATING ENERGY COSTS

A comparison of international energy prices, particularly of heavy fuel oil which accounts for 99% of the energy cost results in the various foreign energy CCFs given in column 7 of Table 18. These factors are computed from a comparison of heavy fuel oil prices and the assumption that different plants around the world use the same amount of fuel as that used in the base-case plant, i.e., 1,924,875 barrels.

The CCFs in column 4 of Table 18 are used for translating energy costs from the United States base-case plant to locations abroad. United States energy costs, which are obtained from appropriate cost curves in earlier sections of this handbook, are multiplied by the appropriate CCF given in column 4 of Table 18. The result is the estimated cost of energy in the country of interest.

As an example, assume the estimated energy cost for the bauxite slurry preparation and digestion process at the United States plant process to be $10 million and that this cost must be translated to India. From Table 18, the appropriate cost factor is 1.26. Thus, the estimated energy cost in India (for the same process) is 1.26 (10) or $12.60 million.

TABLE 18. - Energy prices and conversion factors - 1983

(1) Country	(2) Heavy fuel oil,[1] $U.S./barrel	(3) Energy cost, 10^6 $U.S.[7]	(4) Energy cost factor, U.S.=1.00
Australia	35.97	69.24	1.22
Brazil	24.41	46.99	0.83
Canada	37.64[2]	72.45	1.27
France	27.81	53.53	0.94
Ghana	16.93	32.59	0.57
Greece	26.09	50.22	0.88
Guinea	29.81[3]	57.38	1.01
Guyana	29.81[3]	57.38	1.01
India	37.38[4]	71.95	1.26
Ireland	35.03[2]	67.43	1.18
Italy	30.11	57.96	1.02
Jamaica	28.13	54.15	0.95
Japan	35.11	67.58	1.19
Norway	30.46[2]	58.63	1.03
Spain	24.39	46.95	0.82
Suriname	25.21[5]	48.53	0.85
Taiwan	31.22[6]	60.09	1.06
Turkey	33.23	63.96	1.12
United Kingdom	28.75	55.34	0.97
United States	**29.57**	**56.92**	**1.00**
West Germany	24.21	46.60	0.82
Venezuela	1.78	3.43	0.06
Yugoslavia	34.31	66.04	1.16

[1]Data obtained from US Department of Energy, Energy Information Administration, International Energy Annual 1983, unless otherwise noted.

[2]Data obtained from OECD, Energy Prices and Taxes, May 1983.

[3]Regional price for Africa based on average of Ethiopia, Ghana, Kenya, Morocco, South Africa, and Tunisia as cited in DOE, idem., above.

[4]1981 price obtained from World Bank, The Energy Transition in Developing Countries.

[5]Regional price for South and Central America based on average of Argentina, Brazil, Chile, Dominican Republic, Ecuador, Jamaica, Peru, and Uruguay as cited in DOE, idem., above.

[6]Regional price based on average of Indonesia, Japan, Philippines, Singapore and Thailand as cited in DOE, idem., above.

[7]Calculated on the assumption that 295,000 MT or 1,924,875 barrels of heavy fuel oil--as in the US base case plant--are utilized.

4.5.1.3. TRANSLATION OF DIRECT OPERATING SUPPLIES COSTS

Operating supplies utilized in direct unit operations--as designated in the United States base-case plant--consist primarily of caustic soda, lime, flocculants, hydrochloric acid and sulfuric acid.

Approximately 85% of the total operating supply cost at the United States base-case plant are accounted for by two items: caustic soda and lime. Annual requirements, share of physical volume, United States costs and costs shares for the United States plant are:

MATERIAL	ANNUAL REQUIREMENT (Metric Tons)	WEIGHT SHARE (%)	US COST ($/LB)	ANNUAL MATERIAL COST ($000)	COST SHARE (%)
Caustic Soda	125,000	56.0	220	27,500	82.0
Lime	100,000	44.0	60	6,000	18.0
	225,000	100.0		33,500	100.0

CCFs for operating supplies are calculated on the basis that 82% of the cost of supplies is attributable to caustic soda and the remaining 18% is attributable to lime. To the extent that price data for both elements are not generally available for most of the countries that house alumina refineries, prices for other goods (or group of goods)--which are used as surrogates--are compared. In terms of caustic soda, export/-import prices of goods falling under SITC classification 522.5, inorganic bases, n.e.s., were compared and used to calculate a CCF for caustic soda. In terms of lime, prices of cement at different world locations were compared and used to calculate a CCF for lime. The overall CCF for operating supplies is the appropriately weighted average of caustic soda and lime CCFs. These overall CCFs are given in column 4 of Table 19.

To translate the cost of operating supplies associated with the United States base-case plant, the procedure is simply to multiply it by the CCF for the country to which the cost must be translated. If the cost in the United States is $15 million and must be translated to France (with a CCF of 0.91) the cost in France will be $13.65 million (0.91 x 15 million).

As with some of the other cost elements, local price variations can be substantial, and site-specific costs should be used if available.

TABLE 19. - Operating supply cost conversion factors

(1) Country	(2) Factor for caustic soda,[1] U.S.=1.00	(3) Factor for lime,[2] U.S.=1.00	(4) Overall supply cost factor,[3] U.S.=1.00
Australia	1.00[4]	1.66	1.12
Brazil	0.98	0.64	0.92
Canada	1.10	1.36	1.15
France	0.96	0.68	0.91
Ghana	1.20[5]	1.23	1.21
Greece	0.78	0.60	0.75
Guinea	1.20[5]	1.23	1.21
Guyana	0.95[6]	1.28	1.01
India	1.20	0.84	1.14
Ireland	1.01	1.35	1.07
Italy	1.06	1.22	1.09
Jamaica	0.95	1.28	1.01
Japan	0.84	1.00	0.87
Norway	0.91	1.17	0.96
Spain	1.03	0.63	0.96
Suriname	0.85[7]	1.28	0.93
Taiwan	1.08[8]	1.00	1.07
Turkey	1.05	0.40	0.93
United Kingdom	1.04	1.12	1.06
United States	**1.00**	**1.00**	**1.00**
West Germany	0.99	0.95	0.98
Venezuela	0.85	1.08	0.89
Yugoslavia	1.19	0.49	1.06

[1]Factors calculated on the basis of import/export values of goods falling under the SITC classification #522.5, under which caustic soda is included.

[2]Factors calculated on the basis of cement prices cited in Engineering News Record in recent years.

[3]Weighted on the following basis: caustic soda 82% and lime 18%.

[4]No data available for calculation; figure given is assumed.

[5]Factor calculated on the basis of import data for Egypt, Morocco and Tunisia.

[6]Factor calculated for Jamaica used as a surrogate.

[7]Factor calculated for Venezuela used as a surrogate.

[8]Factor calculated for South Korea used as a surrogate.

4.5.2. TRANSLATION OF GENERAL FACILITY COSTS

General facility costs include costs that cannot be readily allocated to unit operations. Included in this category are labor, energy and supply costs incurred in the operation and maintenance of various support facilities, e.g., warehouses, maintenance shops, utility distribution facilities, laboratories, changehouses, yards and roads, lunchrooms, etc. For more detailed discussion of the elements included in general facility costs, see Section 4.2.

To the extent that general facility costs are subdivided into the three component categories of labor, energy and supplies--estimated at 68.5%, 8.1% and 23.4%, respectively, of general facility costs at the United States base-case plant--cost factors previously derived for these categories under the heading of refining costs (see Section 4.5.1) can be used for translating general facility costs to foreign locations. However, some discussion is in order.

In terms of labor, general facility costs include wages and/or salaries (plus fringes) paid to workers other than those involved in direct unit operations, e.g., grounds keepers (responsible for the upkeep of yards and roads), service personnel (servicing the lunchroom, maintenance shop and change house), laboratory technicians, operating and maintenance supervisory personnel, administrative and "other" personnel, etc.

For translation purposes, the wages earned by general facility laborers are assumed to bear the same relationships to equivalent workers in the United States as do operating workers. Thus, the labor conversion factors given in column 8 of Table 17 of Section 4.5.1 are recommended for use. To translate this cost to a foreign location, say Brazil, for example, the user of the handbook need only choose the appropriate factor given in column 8 and multiply it by the United States cost. According to column 8, the appropriate factor for Brazil is 0.33. Multiplication of this factor by the United States cost results in the estimated cost of general facility labor in Brazil. If translation of supervisory labor-only costs

In summary, the foreign operating labor CCFs presented in Table 17 are also used to translate general facility labor costs to foreign locations.

In terms of energy, general facility energy costs are incurred, largely, in the use of heavy fuel oil. If the amount utilized is assumed constant at all locations, CCF's would then reflect international price differences only. A comparison of heavy fuel oil prices at different world locations--as was also completed in the calculation of energy cost factors in the section on alumina refining costs--results in the CCFs previously given in Table 18.

For translation of general facility energy costs to foreign locations, the handbook user is again directed to column 4 of Table 18. Multiplication of the general facility energy cost associated with the United States plant by the appropriate country factor--as listed in column 4--results in the estimated general facility energy cost in the country of interest.

If translation of general facility energy costs to Japan, for example, were required, the handbook user would simply multiply the United States cost, say $500,000, by the appropriate CCF for Japan, i.e., 1.19. The result, $595,000, is the estimated general facility energy cost in Japan.

In terms of general facility supplies, little or no data are available on prices in foreign countries. Without the data essential to make foreign comparisons, it becomes necessary to assume constant general facility supply costs. Thus, the CCFs needed for the translation of United States general facility supply costs are assumed to be unity for all countries. To the extent that general facility supply costs account for but 3.7% of total operating costs, the error introduced by this assumption will not alter the final estimate of operating costs appreciably. If, for example, general facility supply costs were in error by as much as 50%, ceteris paribus, the overall operating cost estimate would still be within 1.85% of the true value.

4.5.3. TRANSLATION OF ENVIRONMENTAL CONTROL SYSTEMS COSTS

Environmental control systems costs, like refining costs, Section 4.5.1, are broken down into the three component categories of labor, energy and supplies. Insofar as (1) operators of environmental control equipment are likely to earn the same or near equivalent wage as workers employed in direct unit operations, (2) the types of energy employed are likely to be the same, and (3) the supplies used are also likely to be the same, the foreign cost factors developed for labor, energy and supplies under the heading of refining costs can be used to translate environmental control systems costs to foreign locations. Foreign cost factors for labor, energy and supplies are provided in Sections 4.5.1.1, 4.5.1.2 and 4.5.1.3, respectively. The user of the handbook is referred to these sections for CCFs applicable for translating environmental control systems costs.

It is important to note, however, that environmental control requirements vary substantially among the countries studied. Thus, although the CCFs identified above are applicable to cost translation given the assumption that environmental controls are installed, the actual plant environmental control configuration may differ from country to country, as noted in the section on environmental controls.

This page is intentionally blank

REFERENCES

1. Baumgardner, Luke H. and Hough, Ruth A. Ch. in BuMines Minerals Yearbook 1983, v.1,pp.

2. Roskill Information Services Ltd. The Economics of Aluminum, 2nd edition, London, 1985, p. 16.

3. International Primary Aluminum Institute. Statistical Summary, vols. 1-3, London.

4. The World Bank. Case Studies on Industrial Processing of Primary Products. Volume I: Bauxite, Rubber, Tropical Hardwood, Washington, D.C., 1983, p. 18.

5. Keefe, J. ed. Aluminum: Profile of an Industry, New York, 1982, p. 28.

6. Stern, Dr. Arthur C. Air Pollution, Third Edition, v. 5, 1977.

7. TMS-AIME World Symposium on Metallurgy, 1980.

8. EPA, (USA), "Effluent Guidelines and Standards for Non-Ferrous Metals", 1974.

9. State of Bahrain, Ministry of Health. "Pollution Control Limitations", (Guidelines), 1982.

10. The World Bank, Office of Environmental Affairs. "Environmental Guidelines", July 1984.

11. Cheremisionoff, Paul N. and Cheremisionoff, Peter P. Industrial Noise-Control Handbook, 1978.

12. Yen-Chen, "Estimating Plant Costs in the Developing Countries", Chemical Engineering, July 10, 1972, p. 90.

APPENDIX A

CAPITAL COST SUMMARY
ALUMINA FACILITY

DATA							
Location			UNITED STATES				
Capacity:							
Alumina (mtpy)			1000000				
Bauxite (mtpy)	% Alumina	49.0	2125850				
Recovery	% Alumina	96.0					
Red Mud			1084184				
Country Cost Factors			1	1	1	1	
Unit Process Description	Section	Factor	Labor	Materials	Equipment Usage	Equipment	Total
DIRECT CONSTRUCTION COSTS							
REFINING							
BAUXITE SLURRY PREP/DIGEST	3.1.1						
Handling/Storage/Reclaim		0.14	$2,588,835	$2,427,033	$809,011	$2,265,231	$8,090,110
Grinding		0.17	$3,143,586	$2,947,111	$982,370	$2,750,637	$9,823,705
Digestion		0.57	$10,540,257	$9,881,491	$3,293,830	$9,222,725	$32,938,304
Caustic Handling		0.12	$2,219,002	$2,080,314	$693,438	$1,941,626	$6,934,380
CLARIFICATION/FILTRATION	3.1.2						
Clarification/Washing		0.47	$4,677,092	$4,142,567	$1,336,312	$3,207,149	$13,363,121
Filter Press		0.19	$1,890,739	$1,674,655	$540,211	$1,296,507	$5,402,113
Red Mud Filter/Disposal		0.17	$1,691,714	$1,498,375	$483,347	$1,160,033	$4,833,469
Lime Slaking/Storage		0.1	$995,126	$881,397	$284,322	$682,372	$2,843,217
Acid Handling/Storage		0.02	$199,025	$176,279	$56,864	$136,474	$568,643
Settling Aid		0.05	$497,563	$440,699	$142,161	$341,186	$1,421,609
HEAT EXCHANGE/PRECIPITATE and CLASSIFICATION	3.1.3						
Heat Exchange		0.04	$1,281,925	$1,001,504	$440,662	$1,281,925	$4,006,016
Precipitation/Classification		0.78	$24,997,540	$19,529,328	$8,592,904	$24,997,540	$78,117,313
Evaporation		0.18	$5,768,663	$4,506,768	$1,982,978	$5,768,663	$18,027,072
CALCINATION/ALUMINA STG	3.1.4						
Calcination		0.66	$9,036,317	$3,975,980	$1,807,263	$21,325,708	$36,145,268
Alumina Handling		0.34	$4,655,072	$2,048,232	$931,014	$10,985,971	$18,620,290
OXALATE CONTROL	5.1	0	$0	$0	$0	$0	$0
LIME PLANT	5.2	0	$0	$0	$0	$0	$0
Subtotal			$74,182,458	$57,211,735	$22,376,689	$87,363,749	$241,134,630
GENERAL FACILITIES							
General Plant	3.2.1	1	$28,180,033	$17,025,436	$10,567,512	$2,935,420	$58,708,401
Power Supply System	3.2.2	1	$36,018,266	$13,506,850	$7,503,805	$93,047,188	$150,076,110
Material Handling	3.2.3	1	$8,246,320	$8,835,343	$3,239,626	$9,129,854	$29,451,142
Administration Buildings	3.2.4	1	$3,901,480	$2,357,144	$325,123	$1,544,336	$8,128,083
Service Buildings	3.3.5	1	$4,955,020	$3,775,253	$589,883	$2,477,510	$11,797,667

APPENDIX A (Cont.)

CAPITAL COST SUMMARY (Cont.)
ALUMINA FACILITY

Subtotal			$81,301,119	$45,500,026	$22,225,950	$109,134,308	$258,161,403
Direct Construction Costs			$155,483,576	$102,711,761	$44,602,639	$196,498,056	$499,296,033
Transport/Sales Taxes							
Export Country (6%)		0.06					$11,789,883
Ocean Freight (15%)		0					$0
Import Country (6%)		0					$0
Sales Taxes (%)		0.02					$3,929,961
Import Duty		0					$0
Subtotal							$15,719,845
Total Construction Costs							$515,015,877
INDIRECT COSTS							
Construction Management	3.4.2	1					$10,367,577
Engineering,Supervision	3.4.2	1					$37,557,573
Subtotal							$47,925,150
TOTAL FACILITY COST							$562,941,027
OTHER COSTS							
Spare Parts (2.5%)	3.4.3.1	0.025					$12,482,401
Mobile Equipment	3.4.3.2	1					$5,000,000
Office Equipment	3.4.3.3	1					$2,000,000
Start Up Expenses (3.5%)	3.4.3.4	0.035					$17,475,361
Owner Staff (3.5%)	3.4.3.5	0.035					$17,475,361
Miscellaneous (8%)	3.4.3.6	0.08					$39,943,683
Technical (3.5%)		0.035					$17,475,361
Subtotal							$111,852,167
TOTAL PROJECT COST							$674,793,194

APPENDIX B

OPERATING COST SUMMARY
ALUMINA REFINERY FACILITY

DATA		
Location		UNITED STATES
Capacity:		
Alumina (mtpy)		1000000
Bauxite (mtpy)	% Alumina 30.50	3451251
Recovery	% Alumina 96.00	
Digestion (High/Low Temp)	Low	

Country Cost Factors			1	1	1	
Unit Process Description	Section	Factor	Labor	Supplies	Energy	Total
REFINING						
BAUXITE SLURRY PREP/DIGEST	4.1.1					
High Temperature	4.1.1	0	$0	$0	$0	$0
Low Temperature	4.1.1.1	1	$4,534,793	$25,865,158	$24,721,706	$55,121,657
CLARIFICATION/FILTRATION	4.1.2	1	$2,550,543	$6,614,758	$875,105	$10,040,406
HEAT EXCHANGE/PRECIPITATE and CLASSIFICATION	4.1.3	1	$3,103,650	$4,203,081	$6,898,012	$14,204,743
CALCINATION/ALUMINA STG.	4.1.4	1	$4,145,527	$5,194,128	$13,507,240	$22,846,895
OXALATE CONTROL		0	$0	$0	$0	$0
LIME PLANT		0	$0	$0	$0	$0
Subtotal			$14,334,513	$41,877,124	$46,002,064	$102,213,701
GENERAL/ADMINISTRATIVE						
GENERAL PLANT	4.2.1	1	$2,265,874	$776,370	$270,680	$3,312,924
POWER SUPPLY SYSTEM	4.2.2	0	$0	$0	$0	$0
MATERIAL HANDLING	4.2.3	1	$1,172,316	$1,088,685	$67,072	$2,328,073
AMINISTRATIVE SERVICES	4.2.4	1	$2,917,140	$12,295,760	$505,694	$15,718,594
Supervision		1	$4,500,556	$0	$0	$4,500,556
Subtotal			$10,855,886	$14,160,814	$843,446	$25,860,147
ENVIRONMENTAL	4.3	1	$517,258	$233,079	$290,127	$1,040,464
TOTAL OPERATING COSTS			$25,707,656	$56,271,018	$47,135,637	$129,114,311

This page is intentionally blank

APPENDIX C

COST UPDATING

The estimating procedures presented in this handbook, using individual cost component breakdowns, provide a methodology by which the base costs derived from the system can be adjusted to be applicable in different locations and/or be updated through time.

Two methods may be used to update the labor cost curves. Method one, the more accurate of the two, is to use the prevailing labor rates for the area under consideration, in the year of desired escalation, and apply the appropriate payroll burdens and premiums. By dividing the new rate by the one given in the narratives, a labor adjustment multiplier is obtained, which is applied to the labor cost calculated from the formulae or from the curves. The second method is to use a labor rate for the area under consideration, in the base year and update by the Construction Wage Rate Index or the Mining Wage Index. By dividing the index corresponding to the year of desired escalation by the one in January, 1984, a ratio is derived, which is applied to the calculated labor cost. This factor can be used for all classes of labor throughout the estimate.

Most of the supplies and equipment operation costs are composed of more than one component. In these cases, it is necessary to calculate the component cost for each index classification. By dividing the index corresponding to the year of desired escalation by the one for January 1984, for each component, a ratio is obtained which is multiplied by the calculated cost component. Combining these escalated components produces a final updated cost.

Electrical, natural gas, propane, and water costs do not have corresponding index classifications for updating. The method used to update these categories by location is to use the prevailing rates for the area under consideration, either in the base year or the year of desired escalation, and to divide the new rate by the one given in the narratives resulting in the adjustment factor. This factor is next multiplied by the identified corresponding cost from the narrative and curve to obtain the site specific cost.

Cost Indexes

Cost indexes described in this section are a result of work accomplished by others for the U.S. Bureau of Mines.

The Construction Wage Rate Index includes all labor (see mining wage index, above, for inclusions) employed in the construction of mines and mineral processing facilities.

The Construction Materials Index is applicable to materials such as sand, gravel, cement, limestone, reinforcing rods, steel fasteners, etc. for use in construction of mine and mineral processing plants and related infrastructure.

APPENDIX C (Cont.)

COST UPDATING

The Equipment and Repair Parts Index relates to equipment and repair parts relevant to mining and mineral processing operations and related infrastructure, e.g., frontend loaders, shovels, load haul dumps, trucks, jumbo drills, as well as crushers, grinding mills, flotation cells, thickeners, filters, etc.

The Mining Wage Rates Index includes both mine and plant labor. This index includes skilled, unskilled, local and expatriate labor along with burden and fringe benefits (employer's contribution to union funds for health and welfare, vacations, holidays, sick leave and retirement, Social Security, Federal and State Unemployment Insurance, and Workmen's Compensation).

The Industrial Materials Index includes mining and mineral processing chemicals used in daily operations, e.g., wetting agents, mining reagents, dust depressants, flocculants, flotation reagents, etc.

APPENDIX C (Cont.)

COST UPDATING

Table 5. U.S. Cost Indexes, 1980 - 1985

	1980	1981	1982	1983	1984	1985
Construction Wage	2767.0	3025.0	3345.0	3587.0	3734.0	
Construction Materials	287.7	310.3	330.1	352.9	358.8	
Equipment/Repair Parts	288.9	320.8	343.9	351.9	357.9	
Mining Wage	9.19	10.06	10.82	11.27	11.57	
Industrial Materials	274.2	304.1	312.3	315.7	322.1	